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THESIS

COST BENEFIT AND CAPABILITY ANALYSIS OF SEA-BASE CONNECTORS

by

Justin A. Dowd

September 2009

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13. ABSTRACT (maximum 200 words)

In this thesis a cost benefit and capability analysis is conducted on a number of Sea-Base connectors. In conducting this analysis the average yearly Operating and Sustainment (O&S) cost of the connectors studied is used along with specific performance data such as maximum payload (in tons), maximum speed (in knots) when loaded to maximum payload, and maximum range (in nautical miles) when operated at maximum payload and maximum speed to obtain a number of comparative metrics. These metrics include, but are not limited to tons per hour (tph), cost per ton ($/ton) and cost per ton per nautical mile ($/ton-NM).

A number of air and surface connectors were considered consisting of both legacy platforms in use today as well a number of future concept platforms currently being developed. The surface connectors considered are the Landing Craft Air Cushion (LCAC), the Ship-to-Shore Connector (SSC), Joint High-Speed Vessel (JHSV), Landing Craft Utility Replacement (LCU(R)) and the Ultra Heavy-Lift Amphibious Connector (UHAC). The air connectors considered are the MV-22 Osprey, the CH-53E Sea Stallion, the Hybrid Ultra-Large Aircraft (HULA) and the Hybrid Very-Large Aircraft (HVLA).

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COST BENEFIT AND CAPABILITY ANALYSIS OF SEA-BASE CONNECTORS

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LIST OF ACRONYMS AND ABBREVIATIONS

AA	Alternative Architecture
ACU-4	Assault Craft Unit Four
ACV	Air Cushioned Vehicle
ADP	Advanced Development Programs
B–TPH	Baselined Tons per Hour
bbls/hr	Barrels per Hour
bbls/yr	Barrels per Year
BTR	Beach Transfer Rate
C2	Command and Control
CDR	Commander
CNA	Center for Naval Analysis
$/hr	Cost per Hour
$/ton	Cost per Ton
$/ton-NM	Cost per Ton per Nautical Mile
$/trip	Cost per Trip
DoD	Department of Defense
EMW	Expeditionary Maneuver Warfare
FY	Fiscal Year
gal/bbl	Gallons per Barrel
HNS	Host-nation Support
HULA	Hybrid Ultra-large Aircraft
HVLA	Hybrid Very-large Aircraft
JFC	Joint Force Commander
JHSV	Joint High Speed Vessels
JOA	Joint Operations Area
lbs/hr	Pounds per Hour
lbs/yr	Pounds per Year
LAV	Light Armored Vehicle

LCAC	Landing Craft, Air Cushion
LCDR	Lieutenant Commander
LCU	Landing Craft Utility
LCU(R)	Landing Craft Utility, Replacement
MAGTF	Marine Air Ground Task Force
MEB	Marine Expeditionary Brigade
MLP	Mobile Landing Platform
N-$/ton	Normalized Cost per Ton
N-TPH	Normalized Tons per Hour
NAVAIR	Naval Air Warfare Center
NAVSEA	Naval Sea Systems Command
NCAD	Naval Cost Analysis Division
NCCA	Naval Center for Cost Analysis
NCP	Naval Capability Pillars
NM	Nautical Mile
NOC	Naval Operating Concept
NTR	Naval Transformation Roadmap
NWP	Naval Warfare Publication
O&S	Operating and Support
OMFTS	Operational Maneuver from the Sea
ONR	Office of Naval Research
OPNAV	Office of the Chief of Naval Operations
OSCM	Master Chief Operations Specialist
OSR	On Site Representative
PMS	Program Manager Sea
RAND	Research and Development
ROMO	Range of Military Operations
SSC	Ship-to-shore Connector
STOM	Ship-to-objective Maneuver
TPH	Tons per Hour
UHAC	Ultra Heavy-lift Amphibious Connector

U.S.	United States
USMC	United States Marine Corps
USN	United States Navy
VAMOSC	Navy Visibility and Management of Operating and Support Costs
VSTOL	Vertical/Short Takeoff and Landing
WDTR	Well Deck Transfer Rate

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I. INTRODUCTION

While the formalized term of "Seabased" operations is a relatively recent occurrence, the practice of such operations has been carried out by Naval Forces almost since the existence of a U.S. Navy. In fact, as quoted in Naval Warfare Publication (NWP) 3-62M,

> U.S. naval forces have conducted Seabased operations, projecting power from the sea, since the Continental Marines landed from converted merchant ships of the Continental Navy at New Providence in the Bahamas on March 3, 1776. With the development of amphibious doctrine a century and a half later and its execution during the island-hopping campaigns of World War II, Seabased operations seemed to have reached a pinnacle. However, nearly three quarters of a century later, technology and innovative thought have continued to evolve, providing opportunities for tremendous advancements in Seabasing capabilities. This has led to the development of the latest Marine Corps capstone operational concept, expeditionary maneuver warfare (EMW), which incorporates previously published operational concepts, including operational maneuver from the sea (OMFTS) and ship-to-objective maneuver (STOM).[1]

In recent times, many high-level documents and concept papers have been written and distributed regarding the Navy's future vision and operating concept for the conduction of Seabased operations.

> The Navy and Marine corps visions, strategies, and concepts delineated in Naval Power 21, Sea Power 21, Marine Corps Strategy 21, the Naval Operating Concept (NOC) for Joint Operations, EMW, and Naval Transformation Roadmap (NTR) 2003 emphasize Seabasing as the overarching expression of a shared vision, incorporating initiatives that will allow the joint force to fully exploit one of this nation's asymmetric advantages – command of the sea, and the Sea Base as one of four naval capability pillars (NCPs).[2]

> A sea base provides a Joint Force Commander (JFC) with a scalable and mobile capability in the joint operations area (JOA) from which to exercise command and control (C2) and/or provide strike, power

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[1] Navy Warfare Development Command, "Seabasing," Naval Warfare Publication (NWP) 3-62M, August 2006.

[2] Ibid.

projection, fire support, and logistics capabilities from the sea where and when needed. A sea base can be as small as one ship, or it can expand to consist of dozens of ships. This capability minimizes the need to place vulnerable assets ashore early in the operation, and a sea base can be established without reliance on host-nation support (HNS).[3]

Arguably, the most critical capability possessed by any Sea-base is its ability to quickly and efficiently deploy, support and sustain combat forces ashore. Inherent to the success of any operation conducted from a Sea-base is the movement of large quantities of logistical supplies over the horizon from the Sea-base to any or all inland operating areas. The successful execution of this aspect of a Sea-base "requires a large dependence on a variety of air and surface connectors, such as the MV-22 Osprey, CH-53 Super Stallion, Landing Craft Air Cushion (LCACs), Joint High Speed Vessels (JHSVs),"[4] Landing Craft Utility, Replacement (LCU(R)), and Heavy Lift, Hybrid Aircrafts (HULA and HVLA).

The purpose of this thesis is to analyze each Sea-base connector, those currently in use and those technologies being developed to support Seabased operations. This analysis consists of connector comparisons from both a cost benefit approach as well as capability assessments in an attempt to gain insight into which current connectors are best suited for continued use, and which of the new technologies analyzed show the greatest potential.

A.   CONNECTOR CAPABILITY DETERMINATION

The initial process of study is to determine accurate and comparable capabilities for each Sea-base connector studied. The capabilities selected for accomplishment of this comparison for each connector are:

- Maximum Payload in tons.
- Maximum Speed in knots when loaded to maximum payload.

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[3] Navy Warfare Development Command, "Seabasing."

[4] LT Ethel R. S. Bradley, "Physics-Based Modeling and Assessment of Ship-to-Objective Maneuver (STOM) with Air and Surface Connectors," Master's thesis, Naval Postgraduate School, Monterey, California, March 2009.

- Maximum Range in nautical miles when loaded to maximum payload and traveling at maximum speed.

- Average annual operating hours.

B.   COST ESTIMATION

The initial process of study is to develop accurate and comparable cost estimates for each Sea-base connector studied. Because Operations and Support (O&S) costs comprise the vast majority (approximately 80%) of a system's total cost, this cost is selected for use in connector analysis and comparisons for the purpose of this study. Additionally, costs for connectors representing new technologies are difficult to estimate. In the context of this study, the O&S costs for these connectors is more easily obtained or estimated than accurate acquisition or full life-cycle costs, and is used as the cost values throughout this study.

C.   CONNECTOR ANALYSIS

Using the connector capabilities and cost estimates described above, an Excel spreadsheet was developed containing all cost estimates and connector capabilities. Utilizing this spreadsheet, several parameters are developed to affect comparison between connectors. These parameters are:

- Cost per Hour ($/hr)

- Trip Transit Time (hrs)

- Tons per Hour (TPH)

- Cost per Trip ($/trip)

- Cost per Ton ($/ton)

- Cost per Ton per NM ($/ton/NM)

The above stated parameters are utilized in this study to assess each connector's capability with respect to each other and to provide some insight into the relative advantages of some connectors in regards to the others.

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II.   SEA-BASE OVERVIEW

A.   SEA POWER 21

Seabasing is arguably the most important of the three fundamental concepts underlying Sea Power 21. As such, Seabasing is also a principal enabling concept for such documents as the Marine Corps' expeditionary concepts, Expeditionary Maneuver Warfare (EMW), Operational Maneuver from the Sea (OMFTS), and Ship-to-objective Maneuver (STOM).

> Sea Basing is thus one of the key operational concepts that the Navy and the Marine Corps will use to fight and win the littoral conflicts of the 21st century. Sea basing is defined as "enhanced operational independence and support for joint forces provided by networked, mobile, and secure sovereign platforms operating in the maritime domain." —Admiral Vern Clark, former Chief of Naval Operations stated in Sea Power 21 in 2002.

We often cite asymmetric challenges when referring to enemy threats, virtually assuming such advantages belong only to our adversaries. "Sea Power 21" is built on a foundation of American asymmetric strengths that are powerful and uniquely ours.

> The goal of Sea Basing is to protect "joint operational independence" in the largest maneuver area on Earth – the oceans. Sea Basing will give the joint force commander the means to achieve accelerated deployment and employment times for naval power-projection capabilities and enhanced seaborne positioning of joint assets. Sea Basing will minimize the need to build up a logistics stockpile ashore, reduce the operational demand for sealift and airlift assets, and permit forward positioning of joint forces for immediate employment. The overall intent of Sea Basing is to make use of the flexibility and protection provided by the sea base while minimizing the presence of the Marine air ground task force (MAGTF) ashore. The Sea Base consists of numerous platforms to include aircraft carriers, amphibious ships, surface combatants, and the strategic sealift fleet. Sea Basing in Sea Power 21 also provides the following:[5]

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[5] Bradley, "Physics-Based Modeling."

1.   **Seabasing Impact**

- Pre-positioned war-fighting capabilities for immediate employment
- Enhanced joint support from a fully netted, dispersed naval force
- Strengthened international coalition building
- Increased joint force security and operational agility
- Minimized operational reliance on shore infrastructure

2.   **Seabasing Capabilities**

- Enhanced afloat positioning of joint assets
- Offensive and defensive power projection
- Command and control
- Integrated joint logistics
- Accelerated deployment and employment timelines

3.   **Future Seabasing Technologies**

- Enhanced Seabased joint command and control
- Heavy equipment transfer capabilities
- Intra-theater high-speed sealift
- Improved vertical delivery methods
- Integrated joint logistics
- Rotational crewing infrastructure
- International data-sharing networks

4.   **Seabasing Action Steps**

- Enhanced Seabased joint command and control
- Heavy equipment transfer capabilities
- Intra-theater high-speed sealift
- Improved vertical delivery methods
- Integrated joint logistics

B. SEABASING PRINCIPLES

As defined in Naval Warfare Publication (NWP) 3-62M, "Seabasing," seven overarching principles are essential to applying operations from a Sea-base. These principles are[6]:

1. Use the sea as maneuver space. Seabasing exploits the freedom of the high seas to conduct operational maneuver in the maritime environment (to include the littorals) relatively unconstrained by political restrictions. Seabased operations provide a Joint Force Commander (JFC) with the operational flexibility to support the immediate deployment/employment/ sustainment of expeditionary forces across the extended depth and breadth of the battle space.

2. Leverage forward presence and joint interdependence. Joint/coalition forces operating from the Sea-base in conjunction with other globally based joint forces provide a JFC with credible offensive and defensive capabilities during the early stages of a crisis. Forward-deployed joint forces can help to deter or preclude a crisis while enabling the subsequent introduction of additional forces, equipment, and sustainment.

3. Protect joint/coalition force operations. Seabasing provides a layered defense for its forces derived from its freedom of operational maneuver in a maritime environment. The combined capabilities of maritime platforms across all dimensions of the maritime environment (surface, subsurface, air and land) provide the joint forces a defensive shield at sea and ashore. The integration of these capabilities and freedom of maneuver degrades the enemy's ability to successfully target and engage friendly forces while at the same time facilitating joint force deployment, employment and sustainment.

4. Provide scalable, responsive joint power projection. A force rapidly closing the sea base gives a JFC the ability to rapidly scale and tailor forces/capabilities to the mission. A sea base can consist of one ship or dozens of ships, depending on mission requirements. Seabasing provides a JFC the option to mass, disperse, or project joint combat power throughout the operations area at the desired time to influence, deter, contain, or defeat an adversary.

5. Sustain joint force operations from the sea. Seabased logistics entails sustaining forces through an anticipatory and responsive

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[6] Navy Warfare Development Command, "Seabasing."

logistics system to support naval forces afloat and selected joint/coalition forces operating ashore. The sea base is sustained through the interface with support bases and strategic and operational logistics pipelines, enabling naval and selected joint forces to remain on station, where needed, for extended periods of time.

6. Expand access options and reduce dependence on land bases. Seabasing supports global and seabased power projection capabilities to provide a JFC with multiple access options, including unimproved ports and airfields. This will complement forward basing in the Joint Operational Area (JOA), reducing, but not eliminating, reliance on forward basing.

7. Create uncertainty for adversaries. The dispersed and distributed operations of seabasing provide multiple points and means of entry. As a result, an adversary must either disperse forces to cover all possibilities or concentrate forces on what are the most likely or dangerous options, creating opportunities to exploit seams and gaps in defenses.

C.   SEA-BASE SUSTAINMENT

Amateurs discuss strategy; professionals study logistics.[7]

— Anonymous

As defined in Naval Warfare Publication (NWP) 3-62M, "Seabasing," Sea-base sustainment is "the persistent sustainment of selected joint forces afloat and ashore through the range of military operations (ROMO) conducted from the sea base."[8] Logistics is integral to warfare. "Seabased logistics demands a balance between resources and mission requirements to ensure operations can be sustained."[9]

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[7] Systems Engineering and Analysis-6 Cohort, "Seabasing and Joint Expeditionary Logistics," Master's thesis, Naval Postgraduate School, Monterey, California, December 2004.

[8] Navy Warfare Development Command, "Seabasing."

[9] Ibid.

Consistent throughout the seven Seabasing principles detailed above, as well as in Sea Power 21 and other high-level Department of Defense (DoD) Sea-base documents, is the importance of the sustainment phase to the successful conclusion of a particular operation. Imbedded within the sustainment of the Sea-base is the reliance on sea lift for the transportation of logistical supplies from a given forward support base to the Sea-base, and ultimately from the Sea-base out to all Seabased elements within the operating area.

1. Importance of Dedicated Sealift/Airlift

The importance of a dedicated sealift/airlift capability cannot be overstated.

> It allows for the movement and support for U.S. combat forces afloat and ashore. In combat operations in the Arabian Gulf from Desert Shield/Desert Storm in 1990 to Operation Iraqi Freedom in 2003, sealift transported ninety five percent of all supplies to and from the areas of operations.[10]

A 2004 Naval Postgraduate School Master's thesis entitled "Seabasing and Joint Expeditionary Logistics" concluded that a key aspect in the successful mission accomplishment of employing and sustaining combat troops at an inland objective area from a Sea-base was the utilization of a dedicated sealift/airlift capability. Figure 1 shows a comparison of several varying compositions of assets and capabilities as compared against each other for the successful forming of required capabilities at a Sea-base in a specified period of ten days. What should be taken from this figure are that those Sea-base compositions possessing dedicated sealift/airlift capabilities (the alternative architectures shown as AA2 and AA3) are able to meet the stated timeline requirement while the other two alternative architectures are not.

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[10] LCDR Christopher G. Williams, "Physics-Based Modeling and Assessment of Mobile Landing Platform System Design," Master's thesis, Naval Postgraduate School, Monterey, California, September 2008.
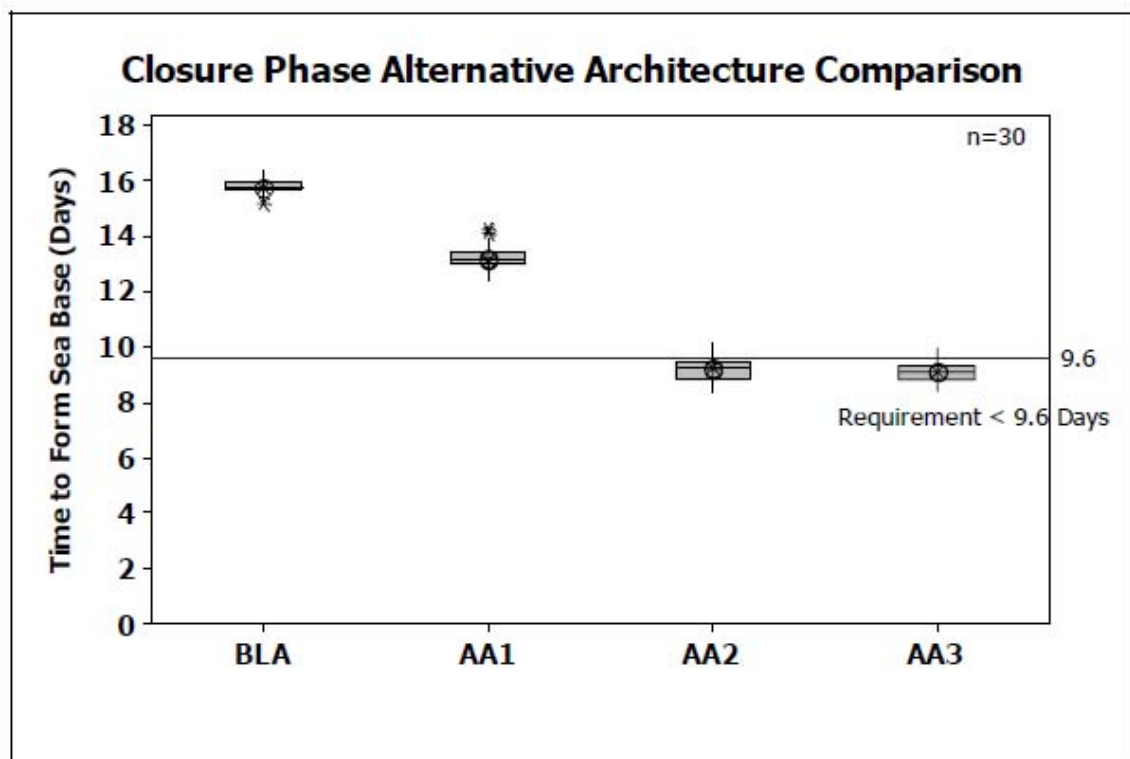
Figure 1.   Comparison of Sea-base Architectures with and without Dedicated Lift.
(From [11])

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[11] Systems Engineering and Analysis – Six Cohort.

III. PLATFORMS

A. SURFACE CONNECTORS

1. Landing Craft Air Cushion (LCAC)

The Landing Craft Air Cushion (LCAC), shown loaded at both the standard 60-ton payload and the 75-ton overload condition in Figures 2 and 3 is the primary surface connector being studied for the transportation of personnel and supplies from the at-sea Sea-base platforms to shore and across the beach as it is an existing technology and widely used by the U.S. Navy for conducting amphibious operations. The LCAC is a high-speed, over-the-beach, fully amphibious landing craft, capable of carrying a 60- to 75-ton payload.[12] The LCAC is designed as a hovercraft "providing the capability to launch amphibious assaults from points over the horizon,"[13] and due to its "over-the-beach capability is accessible to more than 80% of the world's coastlines."[14] For the purposes of this study, the following characteristics are used:

Payload	Speed (Max)	Range
75 Tons	45	96 NM
60 Tons	50	175 NM

Table 1.   LCAC Performance Characteristics. (From[15],[16])

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[12] "Landing Craft, Air Cushion (LCAC)," http://www.globalsecurity.org/military/systems/ship/lcac.htm (accessed March 2009).

[13] Ibid.

[14] Ibid.

[15] Ibid.

[16] Navy Warfare Development Command, "Employment of Landing Craft Air Cushioned (LCAC)," NWP 3-02-12, February 1997.

Figure 2.   Landing Craft Air Cushion (LCAC) at 60-Ton Payload. (From[17])

Figure 3.   Landing Craft Air Cushion (LCAC) at 75-Ton Overload. (From[18])

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[17] Williams, "Physics-Based Modeling."

[18] "Landing Craft, Air Cushion."

2. Ship-to-shore Connector (SSC)

The Ship-to-shore Connector (SSC) is an Air Cushion Vehicle (ACV) and is the future ACV craft for transporting vehicles and cargo from the ship to shore. It is also the planned replacement craft for the current LCAC. The SSC will provide high-speed, over the horizon, heavy lift capability to transport the personnel, equipment, and material of the United States Marine Corps' Marine Expeditionary Brigade (MEB) as established for year 2015.[19]

While a specific SSC has not yet been produced, the following planned characteristics[20] are representative of the design being considered, and will be used for the purpose of this study:

Payload	Speed (Max)	Range
74 Tons	35	86 NM

Table 2. SSC Performance Characteristics. (From [21])

3. Landing Craft, Utility Replacement (LCU(R))

The Landing Craft, Utility Replacement (LCU(R)) is "a landing craft used by amphibious forces to transport equipment and troops to the shore."[22] The LCU(R) is designed with a higher maximum payload than the current LCU 1600 and "will provide a technologically advanced, heavy lift, utility landing craft to complement the high-speed,

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[19] "Ship-to-Shore Connector for Technical Studies," https://www.fbo.gov/index?s=opportunity&mode=form&id=582f8346309854223cb9bf5aaeb35baf&tab=core&_cview=0 (accessed May 2009).

[20] Phone and e-mail conversation with CDR Chris Davis, Surface Connector Requirements, Amphibious Warfare Branch, Expeditionary Warfare Division, N853N, 27 May 2009.

[21] E-mail conversation with CDR Chris Davis, Surface Connector Requirements, Amphibious Warfare Branch, Expeditionary Warfare Division, N853N, 28 May 2009.

[22] "Landing Craft utility (LCU)," http://www.globalsecurity.org/military/systems/ship/lcu.htm (accessed July 2009).

over-the-horizon, ship-to-objective amphibious lift required by Operational Maneuver – From the Sea (OMFTS) and Seabased Logistics."[23] The following characteristics will be used for the purpose of this study:

Payload	Speed (Max)	Range
174 Tons	13	1,000 NM

Table 3.   LCU(R) Performance Characteristics. (From [24])

4.   Ultra Heavy-lift Amphibious Connector (UHAC)

The Ultra Heavy-lift Amphibious Connector (UHAC) is a concept connector being designed to provide a heavy-lift capability and is expected to "provide the ability to transport large amounts of cargo and/or troops from the Sea Base to shore, or directly from the Sea Base to an objective area."[25] The UHAC is expected to provide "an over-the-beach capability with three times the payload of the LCAC as well as three or more times the obstacle clearance of the LCAC."[26] A conceptual rendition of what the UHAC is expected to look like is shown in Figure 4, and the following characteristics will be used for the purpose of this study:

Payload	Speed (Max)	Range
240 Tons	22	200 NM

Table 4.   UHAC Performance Characteristics. (From[27])

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[23] "Landing Craft Utility (LCU), LCU-X/LCU(R)." http://www.globalsecurity.org/military/systems/ship/lcu-x.htm (accessed July 2009).

[24] E-mail conversation with Mr. Larry Johnson, Senior Project Manager, Fulcrum Corporation, 14 July 2009.

[25] Dr. Geoffrey Main, ONR Code 333, "Ultra Heavy-Lift Amphibious Connector (UHAC) INP Concept," 22 May 2009.

[26] Ibid.

[27] E-mail and phone conversations with Mr. Larry Johnson, Senior Project Manager, Fulcrum Corporation, 15–16 July 2009.

14

Figure 4.   Conceptual Depiction of Ultra Heavy-lift Amphibious Connector (UHAC). (From [28])

5.   Joint High Speed Vessel (JHSV)

The Joint High Speed Vessel (JHSV), shown in Figure 5, represents a surface connector possessing greater payload and range than the previous surface connectors described in this report. This vessel can "provide the capability to operationally move and maneuver combat ready unit sets from staging sites into the forward areas, and to provide follow-on sustainment."[29] The following characteristics will be used for the purpose of this study:

Payload	Speed (Max)	Range
600 Tons	35	1,200 NM

Table 5.   JHSV Performance Characteristics. (From[30])

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[28] Main, UHAC INP Concept.

[29] "High Speed Vessel (HSV)," http://www.globalsecutiry.org/military/systems/ship/hsv.htm (accessed March 2009).

[30] E-mail conversation with CDR Chris Davis, Surface Connector Requirements, Amphibious Warfare Branch, Expeditionary Warfare Division, N853N, 28 May 2009.

Figure 5.   Joint High Speed Vessel (JHSV). (From[31])

B.   AIR CONNECTORS

1.   MV-22 Osprey

The MV-22, shown in Figure 6, is a tilt-rotor, vertical/short takeoff and landing (VSTOL), multi-mission aircraft developed to fill multiservice combat operational requirements. The MV-22 is the Marine Corp's assault helicopter in the medium lift category contributing to the dominant maneuver of landing forces, as well as supporting logistical resupply of combat forces in the period following commencement of an amphibious operation. The tilt rotor design combines the vertical flight capabilities of a helicopter with the speed and range of a turboprop airplane.[32] "The ability of the Osprey

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[31]"High Speed Vessel Experimental One (HSV-X1), Joint Venture." https://ryan.delariviere.net/photo/d/15967-2/High_Speed_Vessel_Experimental_One_HSV_X1_Joint_Venture_02.jpg (accessed May 2009).

[32] "High Speed Vessel Experimental One (HSV-X1), Joint Venture."

to self-deploy makes it ideal for Sea Based operations,"[33] and the following characteristics will be used for the purpose of this study:

Configuration	Payload	Speed (Max)	Range
External Cargo	5 Tons	130 kts	50 NM
Internal Cargo	9.75 Tons	225 kts	100 NM

Table 6.   MV-22 Performance Characteristics. (From [34])

Figure 6.   MV-22 Osprey. (From[35])

2.   CH-53E Super Stallion

The CH-53E, shown in Figure 7, is "a shipboard helicopter configured for the lift and movement of cargo and personnel and the external lift of heavy oversized equipment.

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[33] Williams, "Physics-Based Modeling."

[34] Naval Air Systems Command, "NATOPS FLIGHT MANUAL NAVY MODEL MV-22B TILTROTOR," A1-V22AB-NFM-000, 01 October 2006.

[35] Williams, "Physics-Based Modeling."

The CH-53E is the only helicopter capable of lifting some of the newer weapon systems in the Marine Corps' inventory, including the M-198 Howitzer and the Light Armored Vehicle (LAV)."[36] Additionally, the CH-53E is the only helicopter in the Marine Corp that is capable of "retrieving all Marine Corps and most Navy tactical aircraft used today."[37] The following characteristics will be used for the purpose of this study:

Configuration	Payload	Speed (Max)	Range
External Cargo	18 Tons	150 kts	215 NM
Internal Cargo	15 Tons	150 kts	230 NM

Table 7.   CH-53E Performance Characteristics. (From[38])

Figure 7.   CH-53E Super Stallion. (From[39])

3.   Heavy-lift Hybrid Aircrafts

The Lockheed Martin Hybrid Ultra-large Hybrid Aircraft (HULA)[40] and Hybrid Very-large Aircraft (HVLA) represent an emerging technology in the use of hybrid

[36] "CH-53E Super Stallion," http://www.globalsecutiry.org/military/systems/aircraft/ch-53e.htm (accessed March 2009).

[37] Williams, "Physics-Based Modeling."

[38] Naval Air Systems Command, "NATOPS FLIGHT MANUAL NAVY MODEL CH-53E HELICOPTER," A1-H53BE-NFM-000, 15 March 2006.

[39] Williams, "Physics-Based Modeling."

aircrafts in the transportation of larger payloads over longer distances than is achievable by any current aircraft. A theoretical representation of a hybrid aircraft is shown in Figure 8.

"A hybrid aircraft is a cross between a conventional aircraft which uses airflow over the wings to create lift, and a lighter-than-air vehicle, which uses an envelope inflated with a lighter than air gas to create lift."[41] Because a hybrid aircraft has the ability to operate in an area without a dedicated airfield present, similar to conventional vertical lift assets, it is envisioned to positively aid in a Seabasing scenario.

The envisioned differences between the HULA and HVLA, as applicable to this study are the respective payloads, speeds and ranges, as illustrated in Table 8. Other differences between the HULA and HVLA include the number of propulsion engines per aircraft, physical dimensions of each aircraft, volume of the inflatable envelope and physical size of the cargo compartment.

Much like the JHSV, a hybrid aircraft is a capability to provide the follow-on sustainment needed to support combat troops employed at a forward objective area. Unlike any previously described connectors, however, a hybrid aircraft also has the ability to deliver supplies directly to those forward objective areas, bypassing a beach access needed by surface connectors and at a significantly extended range than is currently allowed by legacy air connectors. The following characteristics will be used for the purpose of this study:

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[40] Lockheed Martin Proprietary Information.

[41] Dan Fisher, Lockheed Martin Aeronautics Company, "White Paper – Hybrid Aircraft Survivability," 01 November 2006, Lockheed Martin Corporation. Lockheed Martin Proprietary Information.

Variant	Payload	Speed (Max)	Range
HULA	500 Tons	100 kts	6,000 NM
HVLA	50 Tons	80 kts	2,000 NM

Table 8.   HULA and HVLA Performance Characteristics. (From[42])
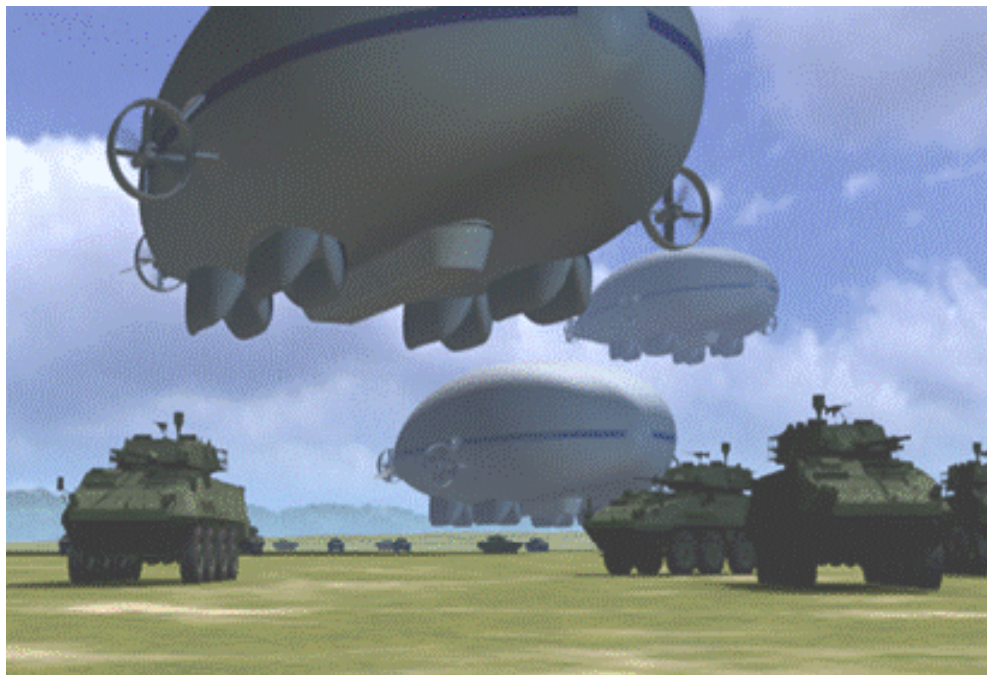
Figure 8.   Hybrid Aircraft Conceptual Design. (From[43])

[42] Fisher, "White Paper – Hybrid Aircraft Survivability," Lockheed Martin Proprietary Information.

[43] Rod Cusic and Robert Boyd, Lockheed Martin Advanced Development Programs "Hybrid Aircraft: A Different Look at Transportation," Lockheed Martin Corporation. Lockheed Martin Proprietary Information.

IV. PLATFORM COST ANALYSIS

A. OVERVIEW

This chapter describes the various steps taken and the sources utilized to provide cost estimates for the various Sea-base connectors considered in this study. This Cost Estimation is "intended to provide insight to the decision-maker regarding the expected costs associated with the logistical component of the Sea-base concept. In addition to decision-maker insights, the cost estimation"[44] of the Sea-base connectors is used to perform comparative studies against one another.

"For the cost estimating process, several assumptions that apply to the overall estimation are necessary."[45] The more important high-level assumptions follow:

- Open source costing data is assumed to be complete and accurate.
- Operating and Support (O&S) Costs make up the majority of a system's cost.
- Only O&S Costs are used for connector comparisons.
- Disposal costs are minimal and do not adversely impact cost estimates.
- Changes in fuel prices affect each connector equally, and relative comparisons remain unchanged.

O&S costs are defined as "all direct and indirect costs incurred in using the delivered system that include the cost of personnel, equipment, maintenance, supplies, software, and services (including contract support) associated with operating, modifying, maintaining, supplying, training, and supporting the defense system."[46]

The most significant cost incurred during the life cycle of a particular system or vehicle is that of the O&S cost, constituting up to 80% of the total life-cycle cost. "This

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[44] Systems Engineering and Analysis-Six Cohort.

[45] Ibid.

[46] Ibid.

cost is directly proportional to the operational life of a given system"[47] Because O&S costs comprise such a majority of total system life costs, it is the cost data used for system comparison in this study.

B. DATA COLLECTION

The first step taken in the cost estimation process is the actual data collection. For the purpose of this study a review of open source literature is conducted to obtain the necessary costing data for the Sea-base connectors detailed in Chapter III. The majority of the cost data contained in this study is obtained from the following sources:

- Navy Visibility and Management of Operating and Support Costs (VAMOSC).[48]
- Global Security website.
- Naval Air Warfare Center (NAVAIR).
- Naval Sea Systems Command (NAVSEA).
- U.S. Navy Fact Files.
- U.S. Marine Corps (USMC) Fact Files.
- Center for Naval Analysis (CNA).
- "Seabasing and Joint Expeditionary Logistics."[49]
- Research and Development (RAND) Corporation.
- Lockheed Martin – Advanced Development Programs (ADP).
- Assault Craft Unit Four (ACU-4).
- Office of Naval Research (ONR).

C. COST ESTIMATE BASELINING

Since the cost data obtained from the appropriate sources listed above are not all given in the same Fiscal Year (FY) dollar amounts, it is necessary to adjust the raw data to a consistent fiscal year in order to conduct accurate and meaningful comparisons. The

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[47] Systems Engineering and Analysis-Six Cohort.

[48] VAMOSC is a restricted access system. Access permission must to granted by the NCAD. The VAMOSC system is located at http://www.navyvamosc.com/ (accessed 02 April 2009).

[49] Systems Engineering and Analysis-Six Cohort.

current fiscal year, fiscal year 2010 (FY10) is selected for use in this study. To account for the inflation in dollar amounts from previous to the current fiscal year values, the Inflation Calculator for FY10 Budget, Version 1[50] was downloaded from the Naval Center for Cost Analysis (NCCA). This calculator is an Excel based program allowing the user to input a dollar amount from any previous year and calculate the corresponding value is FY10 dollars, along with giving the corresponding inflation indices between any two different fiscal years.

D.   COST ESTIMATION

Table 9 provides a summary of the cost estimates used in this report. Dollar amounts are shown in both the fiscal year from which the estimates were obtained as well as in current fiscal year (FY10) dollar amounts. All comparisons between connectors in this study use FY10 dollars as the baseline. As described above, cost figures given in other than FY10 dollars are normalized using the inflation indices obtained from the NCCA calculator.[51]

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[50] Navy Cost Analysis Division (NCAD), http://www.ncca.navy.mil/services/inflation.cfm (accessed April 2009).

[51] Ibid.

Platform	O&S Cost Estimate	Inflation Index	O&S Cost (FY10)
HULA (500 ton payload)	$2,198,119 (FY10$)	1.000	$2,198,119
HVLA (50 ton payload)	$690,000 (FY10$)	1.000	$690,000
MV-22 Osprey	$2,915,003 (FY08$)	1.027	$2,993,708
CH-53 Sea Stallion	$5,118,350 (FY08$)	1.027	$5,256,545
LCAC	$734,500 (FY07$)	1.065	$782,169
SSC	$734,500 (FY07$)	1.065	$782,169
JHSV	$22,300,000 (FY06$)	1.092	$24,344,910
LCU(R)	$1,032,843 (FY09$)	1.017	$1,050,298
UHAC	$1,172,779 (FY10$)	1.000	$1,172,779

Table 9.   Sea-base Connector Cost Summary Table.

1.   Hybrid Aircrafts

All Hybrid Aircraft cost data used in this study is taken from discussions with Mr. Samuel Klooster of Lockheed Martin Corporation's Advanced Development Programs (ADP) Business Development division. The ADP team, working on the hybrid aircrafts, utilizes a total lifecycle cost model to estimate the O&S costs for the Hybrid Very-large Aircraft (HVLA). This cost model is based on industry recognized software,[52] and is assumed to be accurate for the purpose of this study.

As with the O&S data contained in the VAMOSC figures, Lockheed Martin's cost estimates include all associated fuel estimates, anticipated aircraft maintenance and upgrades, and flight crew costs as a function of assumed annual aircraft operating hours.

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[52] Phone and e-mail conversations with Mr. Samuel Klooster, Advanced Development Programs (ADP) – Palmdale, California, Lockheed Martin Corporation (April 2009).

Because the data for both the MV-22 Osprey and CH-53E Super Sea Stallion, as discussed fully in following sections, lists annual per aircraft flight hours at approximately 225 hours/year, this value was also used by Mr. Klooster in obtaining the hybrid aircraft cost estimates as shown in Table 9.

The cost model utilized by Mr. Klooster for the HVLA, provides an estimated yearly (FY10$) O&S cost of approximately $690,000.[53] An approximate fuel consumption rate of 1,450 pounds per hour (lbs/hr)[54] was then converted to a value of 5 barrels per hour (bbls/hr) by dividing the lbs/hr rate by the product of 6.9 pounds per gallon (lbs/gal)[55] and 42 gallons per barrel (gal/bbl).[56] This value was then multiplied by the current cost of aviation fuel of $65/barrel[57] to obtain the estimated annual fuel consumption of 10,093 barrels per year (bbls/yr). Multiplying this estimate by the assumed value of 225 flight hours per year, as described above, an annual fuel estimate of $73,175 per year was obtained. Subtracting this value from the total O&S estimate of the HVLA gives a remaining value of $616,825. Both of these values will be used in estimating the yearly O&S cost for the Hybrid Ultra-large Aircraft (HULA).

As there is no specific model for obtaining direct O&S cost estimates for the HULA as there is for the HVLA, an approximation to this cost for the HULA was made by multiplying the remaining HVLA O&S costs of $616,825 by a factor of 2.5[58] to obtain a value of $1,542,063, and then adding the estimated annual HULA fuel cost of $656,056 for a total yearly O&S estimate for the HULA of $2,198,119. An approximate fuel consumption rate of 13,000 lbs/hr was converted to the annual fuel cost of $656,056 utilizing the same procedure and conversion factors as described above for the HVLA.

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[53] Phone and e-mail conversations with Mr. Samuel Klooster.

[54] Ibid.

[55] "Online Conversions," http://www.onlineconversion.com (accessed April 2009).

[56] VAMOSC.

[57] International Air Transport Association, Jet Fuel Price Monitor, http://www.iata.org/whatwedo/economics/fuel_monitor/index.htm (accessed April 2009).

[58] Phone and e-mail conversations with Mr. Samuel Klooster, Advanced Development Programs (ADP) – Palmdale, California, Lockheed Martin Corporation, April 2009.

2. MV-22 Osprey

The O&S costs for the MV-22 Osprey are taken from the VAMOSC database,[59] and only the data for FY 2008 is used. The database contains O&S costs for the MV-22 from FY 2000 through FY 2008, but only from FY 2006 are the number of aircraft in inventory and reported annual flight hours significant enough to consider the cost data reported as truly representative. Additionally, the change in cost over the last two years of reported data most closely follows the change expected when the appropriate inflation indices are included. For these reasons, the FY 2008 cost data is deemed to be as accurate and representative as available, and is used as such in this study.

For the FY 2008 data, the VAMOSC database shows a total of 63 aircraft in inventory and a total number of flight hours flown as 13,897. This results in the average per aircraft flight hours to be approximately 221. The total fuel consumed in barrels, total fuel costs and total O&S costs are also listed in the database as 10,093 barrels, $11,653,033 and $183,645,216 respectively. Each value was divided by the total aircraft numbers to arrive at the average per aircraft cost in FY 2008 dollars. This value was then converted to current FY 2010 dollars by applying the appropriate inflation index as found in the NCCA calculator,[60] resulting in the values shown in Table 9.

3. CH-53E Super Stallion

The O&S costs for the CH-53E Super Stallion are taken from the VAMOSC database,[61] and only the data for FY 2008 is used. The database contains O&S costs for the CH-53E from FY 1999 through FY 2008, and since the general trend of the cost increase matches fairly closely with expected yearly inflation rates. Because of the overall consistency of the data, and because this aircraft has been inventory for over a decade the FY 2008 cost data is deemed to be as accurate and representative as available, and is used as such in this study.

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[59] VAMOSC.

[60] Navy Cost Analysis Division.

[61] VAMOSC.

For the FY 2008 data, the VAMOSC database shows a total of 144 aircraft in inventory and a total number of flight hours flown as 30,116. This results in the average per aircraft flight hours to be approximately 210. The total fuel consumed in barrels, total fuel costs and total O&S costs are also listed in the database as 324,285 barrels, $24,749,534 and $737,042,342 respectively. Each value was divided by the total aircraft numbers to arrive at the average per aircraft cost in FY 2008 dollars. This value was then converted to current FY 2010 dollars by applying the appropriate inflation index as found in the NCCA calculator,[62] resulting in the values shown in Table 9.

4. Landing Craft Air Cushion (LCAC)

The O&S costs for the LCAC are taken from costing data provided by Master Chief Operations Specialist (OSCM) Donald Buchanan, Senior Craftsmaster at Assault Craft Unit Four (ACU-4) based out of Little Creek, Virginia. The total O&S cost provided by OSCM Buchanan of $23,504,000 was divided by the total number of operational LCACs (thirty-two) available to ACU-4 in 2007 to arrive at an average per vessel cost of $734,500. The cost data provided by OSCM Buchanan is given in FY 2007 dollars, which is then converted to current FY 2010 dollars by applying the appropriate inflation index as found in the NCCA calculator,[63] resulting in the values shown in Table 9.

5. Ship-to-shore Connector (SSC)

The yearly O&S cost for the Ship-to-shore Connector (SSC) are assumed to be identical to the cost estimate for the LCAC. This assumption is based on e-mail conversations with Mr. Jeffrey Kent, LCAC and SSC Requirements Office, OPNAV N853L. Mr. Kent indicated the belief that the SSC will ultimately have approximately a 5-8% cost reduction over the LCAC based on more efficient, better performing engines, but that those estimates could not be confirmed and therefore the LCAC estimates are utilized for the purpose of this study, and are shown in Table 9.

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[62] Navy Cost Analysis Division.

[63] Ibid.

6.   Joint High Speed Vessel (JHSV)

The O&S costs for the JHSV are taken from a Center for Naval Analysis article titled "Cost-Benefit Methodology for Seabasing and Expeditionary Lift."[64] This study utilizes a 2005 Research and Development (RAND) Corporation report titled "Joint High-Speed Vessel Analysis of Alternatives," which provides O&S cost estimates for a wide range of potential JHSV designs including monohull, catamaran and trimaran hull forms. The CNA article takes the overall O&S average for all designs provided in the RAND study, which range from $9,700,000 to $40,300,000, and calculates that average as $22,300,000 in FY 2006 dollars. The FY 2006 values were then converted to current FY 2010 dollars by applying the appropriate inflation index as found in the NCCA calculator,[65] resulting in a value of $24,344,910.

7.   Landing Craft Utility, Replacement (LCU(R))

The O&S costs for the Landing Craft Utility, Replacement (LCU(R)) are derived from costing data provided by Mr. Glenn F. Long, LCU Program OSR, PMS 377J. Mr. Long's data lists the average per hour operating cost for the current LCU platform at $1,865, as well as the average per craft operating hours used in the establishment of this value as 600 hours per year, resulting in an average yearly O&S cost of $1,118,727. The yearly operating hours for the LCU(R) are assumed to be the same as for the current LCU and based on a Center for Naval Analysis article titled "LCU Replacement Analyses of Alternatives,"[66] the LCU(R) cost estimates are approximately 85% of the LCU costs. This percentage is utilized to achieve the initial cost estimate for the LCU(R) of $950,915. This cost estimate is given in FY 2009 dollars, and is then converted to current FY 2010 dollars by applying the appropriate inflation index as found in the NCCA calculator,[67] resulting in the value seen in Table 9.

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[64] Dana S. Partos and James S. Kurtz, Center for Naval Analysis, "Cost-Benefit Methodology for Seabasing and Expeditionary Lift," CAB D0014180.A2/Final, July 2006.

[65] Pete Kusek, et al., "LCU Replacement Analyses of Alternatives," Center for Naval Analysis (CNA), CRM D0005604.A4/1Rev, August 2002 .

[66] Partos, et al., "Cost-Benefit Methodology."

[67] Navy Cost Analysis Division.

8. Ultra Heavy-lift Amphibious Connector (UHAC)

The O&S costs for the Ultra Heavy-lift Amphibious Connector (UHAC) are derived from a combination of the O&S costs for both the LCAC and LCU(R). From phone and e-mail conversations with Mr. Larry Johnson, Senior Program Manager, Fulcrum Corporation, the UHAC is expected to cost somewhat more than the LCU(R) to operate and maintain, but not to the level seen for the LCAC. Additionally, the UHAC is expected to be operated more closely to the annual hours of the LCU(R). As specific estimates have not yet been established for the UHAC, the decision is made to base UHAC cost estimates from 80% of LCU(R) costs and the remaining 20% coming from the LCAC estimates. This estimate becomes [LCU(R) cost per hour * 0.80] + [LCAC cost per hour * 0.20] for a total cost per hour estimate of $2,332. The same 80% is applied to the LCU(R)'s annual operating hours to arrive at the UHAC estimate of 480 hours per year. Multiplying the UHAC cost estimate by its annual operating hour estimate results in an annual O&S cost estimate of $1,119,459 as shown in Table 9.

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V. CONNECTOR COST BENEFIT AND CAPABILITY ANALYSIS

A. INTRODUCTION

In order to conduct any type of meaningful analysis between the various connectors studied in this report it is not only necessary to establish reasonable cost estimates for the connectors but also to determine appropriate metrics for use in comparison. Reasonable cost estimates for each Sea-base connector considered are as discussed in Chapter IV. From these, the next step is to determine what metrics are appropriate for connector comparisons. Because each connector studied has a different maximum speed, range and payload, simply comparing any of those characteristics would not result in any meaningful comparisons. Since values for average annual Operation and Support (O&S) costs, range, speed, and payload are available for each connector, appropriate metrics for connector comparisons must be established as functions of some or all these parameters.

The following metrics are established and results are as shown in Table 10.

- Cost per Hour ($/hr)

- Trip Transit Time (hrs)

- Tons per Hour (TPH)

- Cost per Trip ($/trip)

- Cost per Ton ($/ton)

- Cost per Ton per NM ($/Ton-NM)

- Normalized Cost per Ton (N-$/ton)

- Normalized Tons per Hour (N-TPH)

In all metric derivations involving cost data, the cost used is the fiscal year (FY) 2010 O&S cost as listed in Table 9 in Chapter IV. The details of how these metrics are derived are discussed in detail in the sections below.

B. METRIC ESTABLISHMENT

The Hybrid Ultra-large Aircraft (HULA) is used as the example platform for demonstrating the process by which each of the following metrics are derived and calculated. The same process is used for all connectors based on the specific cost and capability values of each connector.

1. Cost per Hour ($/Hour)

This metric is derived by dividing the FY 2010 O&S cost, as detailed in Chapter IV, by the connector's averaged or estimated annual operating hours. This value represents, roughly, the hourly cost of operating the connector, given the associated value for annual operating hours.

$$\$ / hour = \$2,198,119 / 225 hours$$

$$\$ / hour = \$9,769$$

2. Trip Transit Time (Hrs)

This metric is derived by dividing a connector's maximum range in nautical miles (NM) by its speed in knots (kts). These quantities are as detailed in Chapter III. This represents the average time a connector will take to deliver its maximum payload when operated at its designed transit speed.

$$hours = \frac{6000 NM}{100 kts}$$

$$hours = 60$$

Platform	FY10$ (Used)	Cost ($/hr)	R/V (hrs)	Tons/Hour (TPH)	Cost ($/Trip)	Cost ($/Ton)	Cost ($/Ton-NM)	Baselined [tons]/[hr]	Baselined [tons]/[$]	norm. [$]/[ton]	norm. [tons/[hr]
HULA	$2,198,119	$9,769	60.00	8.33	$586,165.07	$1,172.33	$0.20	1,000.00	0.10236025	0.01	76.92
HVLA	$690,000	$3,067	25.00	2.00	$76,666.67	$1,533.33	$0.77	80.00	0.02608696	0.04	6.15
MV-22 (External)	$2,993,708	$13,546	0.38	13.00	$5,210.07	$1,042.01	$20.84	13.00	0.00095968	1.00	1.00
MV-22 (Internal)	$2,993,708	$13,546	0.44	21.94	$6,020.53	$617.49	$6.17	43.88	0.00323892	0.30	3.38
CH-53 (External)	$5,256,545	$25,031	1.43	12.56	$35,878.01	$1,993.22	$9.27	54.00	0.00215731	0.44	4.15
CH-53 (Internal)	$5,256,545	$25,031	1.53	9.78	$38,381.13	$2,558.74	$11.12	45.00	0.00179776	0.53	3.46
LCAC (60T)	$782,169	$5,214	3.50	17.14	$18,250.61	$304.18	$1.74	60.00	0.01150646	0.08	4.62
LCAC (75T)	$782,169	$5,214	2.13	35.16	$11,124.18	$148.32	$1.55	67.50	0.01294477	0.07	5.19
SSC	$782,169	$5,214	2.46	30.12	$12,812.67	$173.14	$2.01	51.80	0.00993391	0.10	3.98
JHSV	$24,344,910	$8,088	34.29	17.50	$277,303.20	$462.17	$0.39	420.00	0.05192872	0.02	32.31
LCU(R)	$1,050,298	$1,750	76.92	2.26	$134,653.60	$773.87	$0.77	45.24	0.02584409	0.04	3.48
UHAC	$1,172,779	$2,443	9.09	26.40	$22,211.72	$92.55	$0.46	105.60	0.04322042	0.02	8.12

Table 10.   Sea-base Connector Cost Metrics.

3.   Tons per Hour (TPH)

This metric is derived by dividing a connector's maximum payload in tons by its trip transit time in hours. This represents the average per hour rate at which a connector transports its payload if loaded to maximum capacity and operated under the conditions described in the derivations above.

$$TPH = \frac{500tons}{60hrs}$$

$$TPH = 8.33tons / hr$$

4.   Cost per Trip ($/Trip)

This metric is derived by taking the product of a cost per hour value and its trip transit time. This value represents the rough cost for a connector to deliver its maximum payload the maximum range at designed transit speed.

$$\$/trip = \frac{\$9,769 / hr * 6000NM}{100NM / hr}$$

$$\$/trip = \$586,165.07$$

5.   Cost per Ton ($/Ton)

This metric is derived by dividing a connector's cost per trip value by its maximum payload value in tons. This value represents an estimated cost in dollars per ton for a connector moving its maximum payload its maximum range at designed transit speed.

$$\$/ton = \frac{\$586,165.07 / trip}{500ton}$$

$$\$/ton = \$1,172.33$$

6. Cost per Ton per Nautical Mile ($/Ton/NM)

This metric is derived by dividing a connectors cost per ton value by its maximum range in NM. This value represents a rough estimate of how cost effective a connector can be in delivering its maximum payload over its maximum designed range.

$$\$/ton/NM = \frac{\$1,172.33}{6000NM}$$

$$\$/ton/NM = \$0.20$$

7. Baselined Tons per Hour (B-TPH)

This metric is derived by first taking the product of a connector's payload in tons and its speed in knots, resulting in a quantity with units of ton-NM/hour. This value is then divided by the connector's range having the smallest value. In this case the shortest range possessed by any connector is that of 50 NM for the MV-22 when carrying external cargo as seen in Chapter III. This value of range was chosen in order to do a fair comparison between all connectors at the same range. The result of this calculation provides a value of tons per hour which then can be used to compare each connector against each other.

$$B-TPH = \frac{500tons*100knots}{50NM}$$

$$B-TPH = 1,000tons/hour$$

8. Normalized Cost per Ton (N-$/Ton)

This metric is derived by first dividing a connector's N-TPH value by its $/hr value, resulting in a value with units of tons per dollar (tons/$). This value was then inverted to obtain a value with units of dollars per ton ($/ton). Finally, this value of $/ton was divided by the value of the MV-22 when carrying external cargo. This automatically set the MV-22's value to that of unity, providing a standard way to compare all other connectors to each other.

$$N - \$ / ton = \dfrac{1}{\left[\dfrac{0.1023 tons / \$}{0.00096 tons / \$} \right]}$$

$$N - \$ / ton = \$0.01 / ton$$

9. Normalized Tons per Hour (N-TPH)

This metric is derived by first dividing a connector's N-TPH value by the value of the MV-22 when carrying external cargo. As with the normalized cost per ton calculation, this automatically sets the MV-22's value to that of unity, providing a standard way to compare all other connectors to each other on a tons per hour basis.

$$N - TPH = \dfrac{1,000 TPH}{13 TPH}$$

$$N - TPH = 76.92 tons / hour$$

C. OVERALL CONNECTOR ANALYSIS AND COMPARISONS

As described in the previous sections, several different metrics were derived to assist in the comparison of the various Sea-base connectors. Not all metrics developed lend themselves to direct comparison or analysis, but are instead used to further develop other, more appropriate comparative metrics. The following sections contain the pertinent metrics used for connector comparisons, and the results of these comparisons.

1. Cost per Hour ($/Hour) Comparison

As detailed in Section B, this metric provides a means of comparing the per hour cost of operating a given connector. Figure 9 shows a graphical comparison of this metric for the complete range of connectors studied. Worth noting, is that the value as calculated in Table 10 is only valid for the reported annual operating hours of the connector. Based on conversations with Mr. Sam Klooster of Lockheed Martin's Advanced Development Programs (ADP) division, the specific per hour cost of a vehicle generally decreases as its yearly operations increase. This is due to certain maintenance and training costs that are relatively fixed quantities and do not vary with operating hours. As a result, when a connector is operated a relatively low number of hours per

year, these fixed costs are distributed over a smaller number of hours than they would be if the same connector were operated more throughout the year. To illustrate this point, the cost per hour for the Hybrid Very-large Aircraft (HVLA) as shown in Table 10 is $3,067. As provided by Mr. Sam Klooster, this value decreases to less than $900 per hour of operation when the HVLA is operated at approximately 3,000 hours annually, and further reduced to less than $700 per hour when operated at approximately 6,000 hours annually.
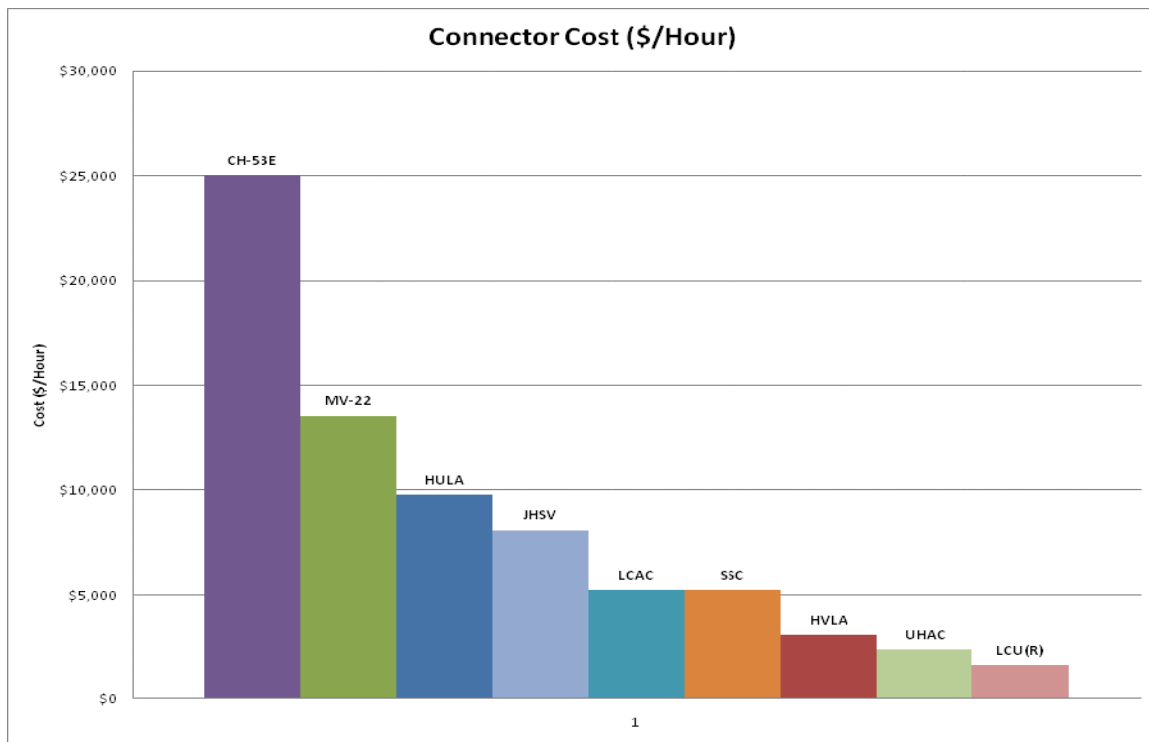
Figure 9.   Connector Cost per Hour Plot.

While the per hour cost of operation does generally decrease with an increase in operational use, expenses such as fuel consumption and general connector wear and tear also increase as usage increases, and for any fixed interval of increased operational usage, the margin of per hour cost savings is not a linear relationship. Though outside the scope of this study, there is a theoretical optimum relationship between annual operational hours and per hour cost for each connector, and it is believed this value would vary between connectors. For the purposes of this study, the per hour cost values as calculated in Table 10 are used in this section as well as subsequent sections requiring their use.

2. Tons per Hour (TPH) Comparison

As detailed in Section B, this metric provides a means of comparing the average tons per hour value of a given connector when operated at its maximum payload, range and speed. Figure 10 shows a graphical comparison of this metric for the complete range of connectors studied.
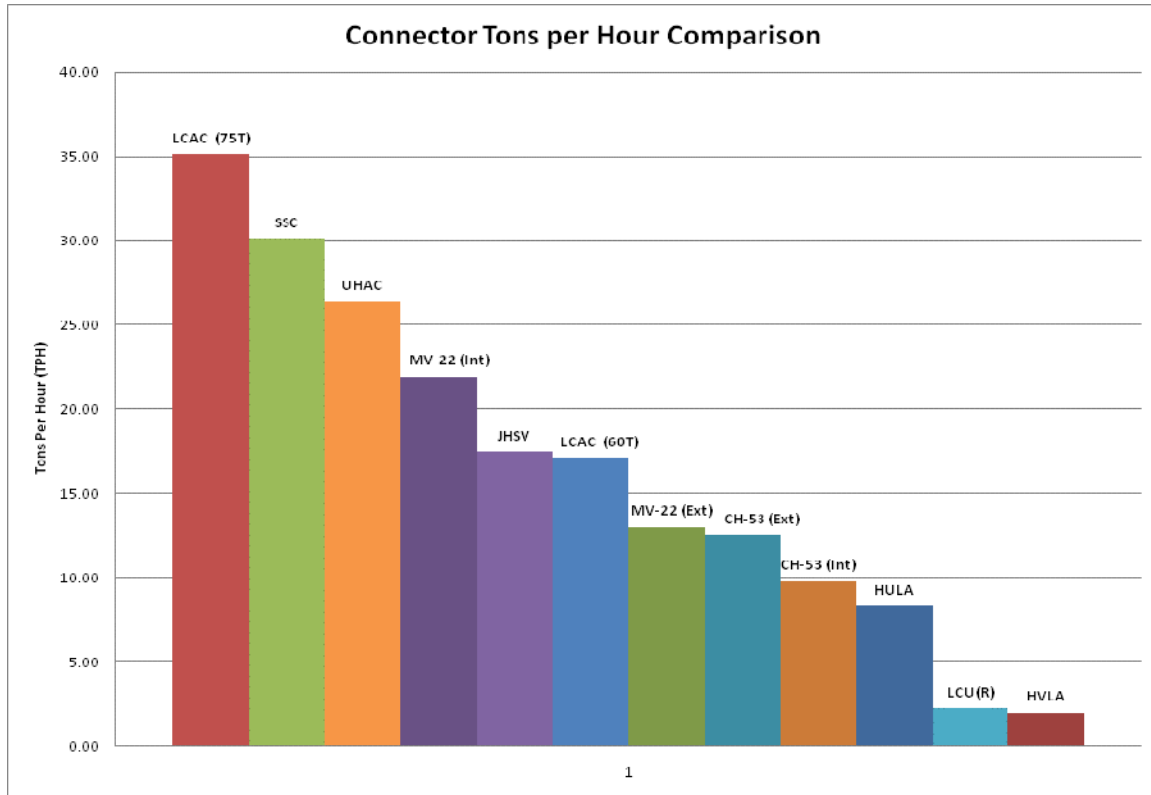

Figure 10.   Connector Tons per Hour Plot.

From the results of this comparison, connectors such as the Landing Craft Air Cushion (LCAC) when loaded to a 75-ton payload and the Ship-to-shore Connector (SSC) show as having the largest tons per hour values.

3. Cost per Ton ($/Ton) Comparison

As detailed in Section B, this metric provides a means of comparing the per ton cost of operating a given connector at its maximum payload, range and speed. Figure 11 shows a graphical comparison of this metric for the complete range of connectors studied. Worth noting here are the connectors showing the lowest per ton cost of operation, differ somewhat from the results of the per hour cost comparison above.

Figure 11.   Connector Cost per Ton Plot.
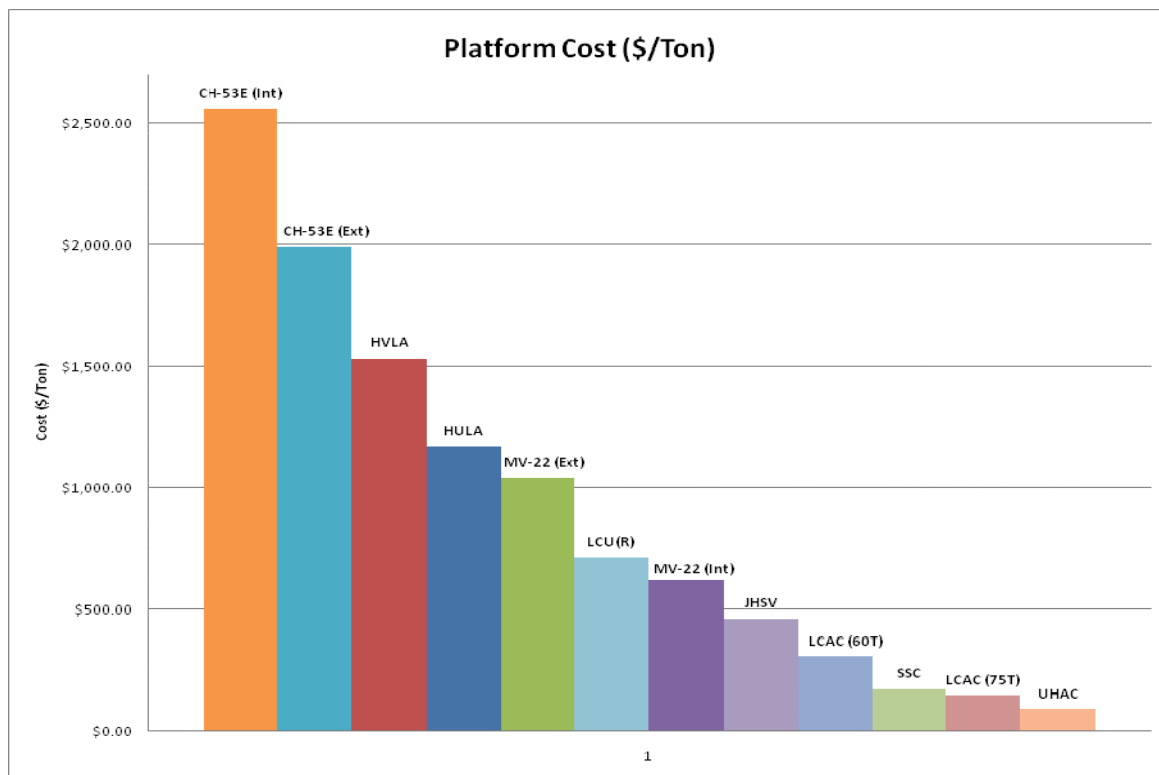
From the results from this comparison, connectors such as the Lansing Craft, Air Cushion (LCAC) loaded to a payload of 75 tons, or the Ship-to-shore Connector (SSC) show as having the lowest cost per ton values, while connectors such as the Landing Craft, Utility Replacement (LCU(R)), or the Hybrid Very-large Aircraft (HVLA) show as having the lowest cost per hour values.

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4. Cost per Ton per NM ($/Ton-NM) Comparison

As detailed in Section B, this metric provides a means of comparing the cost per ton per NM of a given connector as operated at its maximum payload, range and speed. Figure 12 shows a graphical comparison of this metric for the complete range of connectors studied. Additionally, in the realm of commercial shipping for cargo shipped by air, rail, truck or ocean-going vessels, this metric is a common means of expressing the cost of each method of shipping.
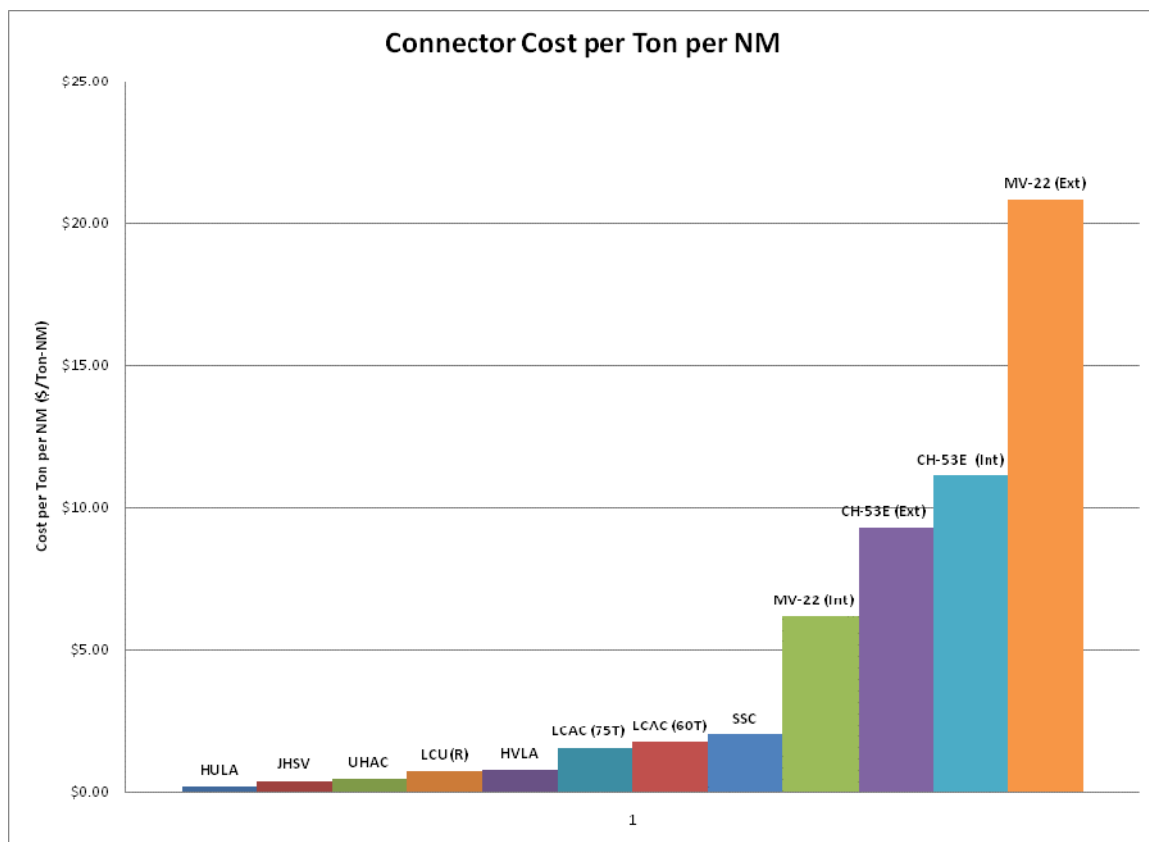

Figure 12.   Connector Cost per Ton per NM Plot.

From the results from this comparison, connectors such as the HULA, Joint High Speed Vessel (JHSV), the UHAC or the HVLA show as having the lowest cost per ton per NM values, while connectors such as the MV-22 and CH-53E show as having the highest cost per ton per NM values.

Because the connector performing the best as seen from the previous four comparisons is not consistently the same, it is necessary to utilize metrics that combine more that a single performance characteristic of a connector. The metrics used for these comparisons are: Normalized Cost per Ton and Normalized Tons per Hour. In this regard, utilizing these metrics provide a more balanced comparison of a given connector's potential value as compared to other connectors.

5. Normalized Cost per Ton (N-\$/Ton) vs. Normalized Tons per Hour (N-TPH) Comparison

As described in Section B, these metrics combine all significant cost and performance characteristics of the connectors studied, and Figure 13 provides a graphical comparison of N-\$/ton plotted against N-TPH. In effect, this provides the ability to assess a given connector's Operational Cost vs. its Operational Capability and quickly see where any given connector ranks in relation to the others.

From the results from this comparison, connectors such as the HULA and JHSV show as having the lowest relative operational cost (N-\$/ton) and the highest relative operational capability (N-TPH). What is somewhat misleading from this graph is that not all connectors studied and included in this comparison have the ability to transit directly to an inland objective. Connectors such as the JHSV, LCU(R) do not possess the ability to deliver their cargo inland. The LCU(R) is able to deliver its cargo directly to the beach, but relies on traditional ground transport vehicles to move the cargo from the beach to the desired objective area. The JHSV is somewhat more constrained in that it requires a dedicated port facility to offload its cargo, as depicted in Figure 14. As with the LCU(R), once the cargo is offloaded from the JHSV there is still a reliance on traditional ground transport vehicles to move the cargo to a desired objective area.
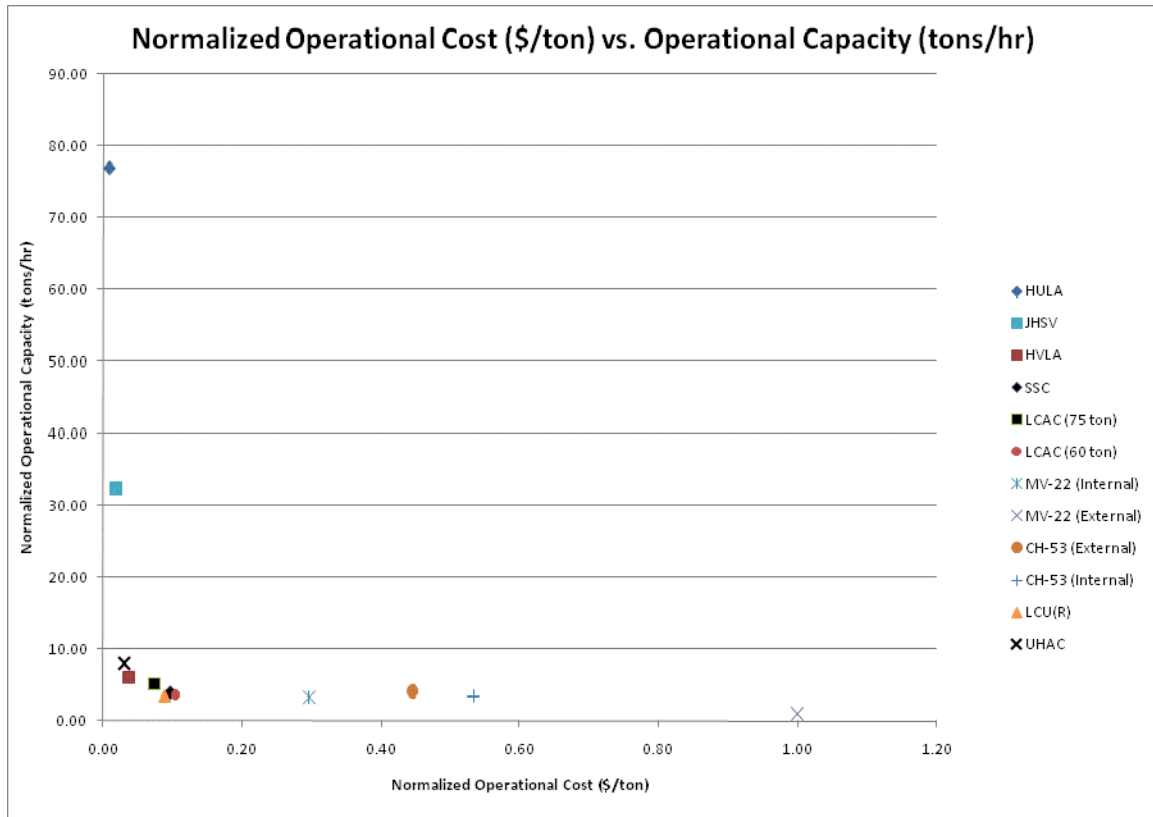
Figure 13.   Normalized Cost per Ton vs Normalized Tons per Hour Plot.

Because the connector comparison in Figure 13 shows such a wide spread in connector capabilities, additional comparisons were conducted utilizing the same metrics (N-$/ton and N-TPH) but only between the various surface connectors and again between only the various air connectors. This additional breakdown is done to more accurately and fairly compare connectors against each other since the air and surface connectors capabilities are seen to be so vastly different.

Figure 14.   JHSV Offloading Cargo to Pier. (From[68])

6.   Normalized Cost per Ton (N-$/Ton) vs. Normalized Tons per Hour (N-TPH) Comparison of Surface Connectors

Again, the metrics used here are the same as described in the previous section, and Figure 15 provides a graphical comparison of N-$/ton plotted against N-TPH for the various surface connectors studied.

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[68] High-Speed Vessel 2, SWIFT, Offloading Cargo to a Pier, http://www.globalsecurity.org/military/systems/ship/images/hsv-2_050130-n-8629m-095.jpg (accessed 21 July 2009).

Figure 15.   Normalized Cost per Ton vs Normalized Tons per Hour Plot of Surface
Connectors.

Not surprisingly, from the results from this comparison, the connector possessing the lowest relative operational cost (N-$/ton) and the highest relative operational capability (N-TPH) is the JHSV. However, as described in the previous section, the JHSV does not have the capability to off load its cargo except at an established port facility. Eliminating the JHSV from this discussion, the UHAC emerges as the most capable surface connector of those studied in this report, as illustrated in Figure 16. Its operational cost is less than half that of the other connectors and provides approximately half again the operational capability of the other connectors. Connectors such as the LCAC when loaded to a 60-ton payload do not fare as well compared to the other surface connectors.

Figure 16.   Normalized Cost per Ton vs Normalized Tons per Hour Plot of Surface
Connectors (Without JHSV).

7.   Normalized Cost per Ton (N-$/Ton) vs. Normalized Tons per Hour (N-TPH) Comparison of Air Connectors

As with the previous sections comparisons, the same metrics are used in comparing the various air connectors studied and Figure 17 provides a graphical comparison of this comparison.
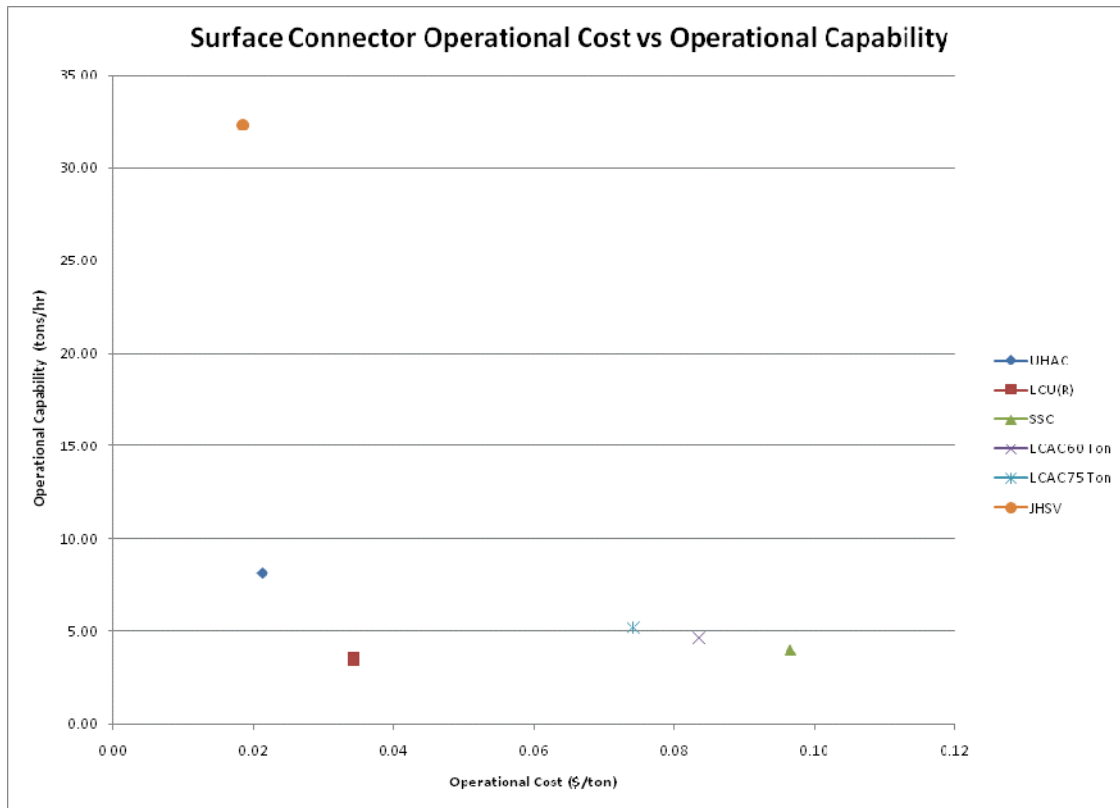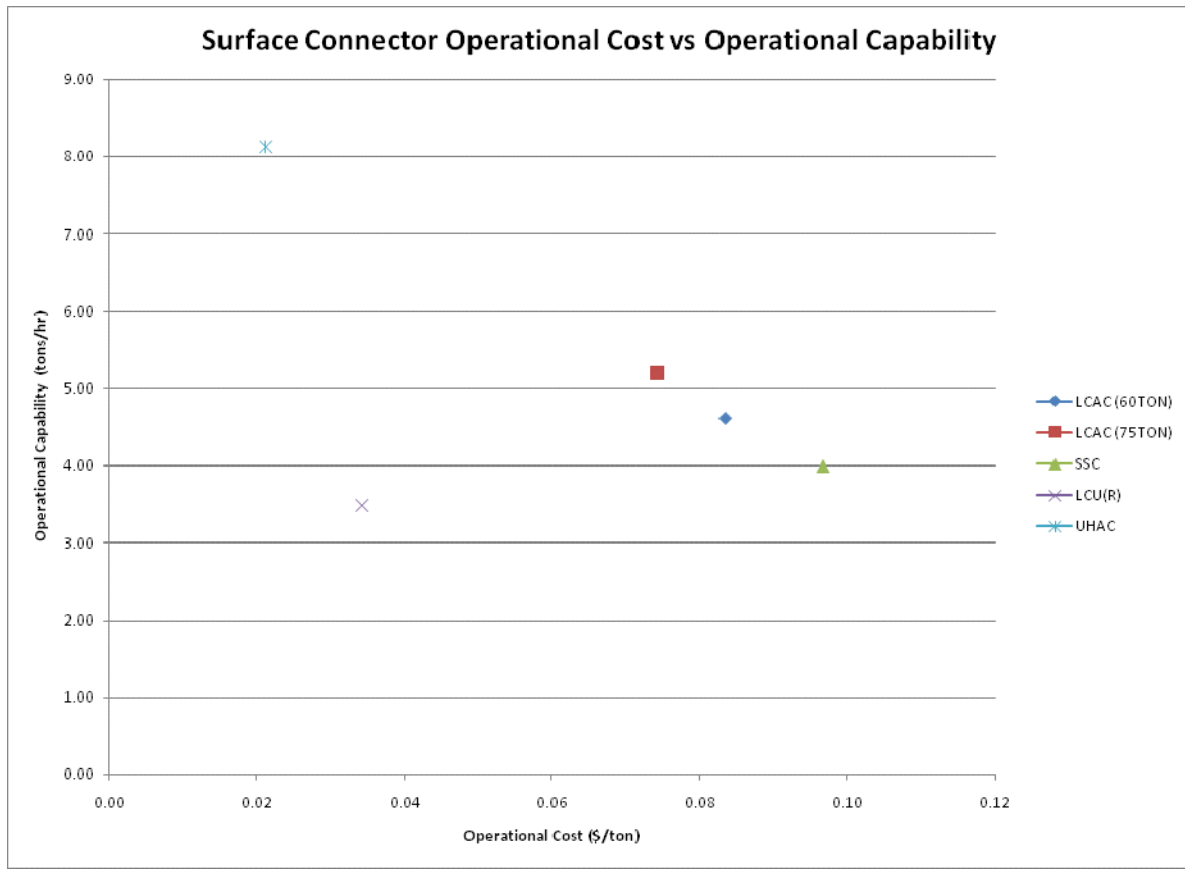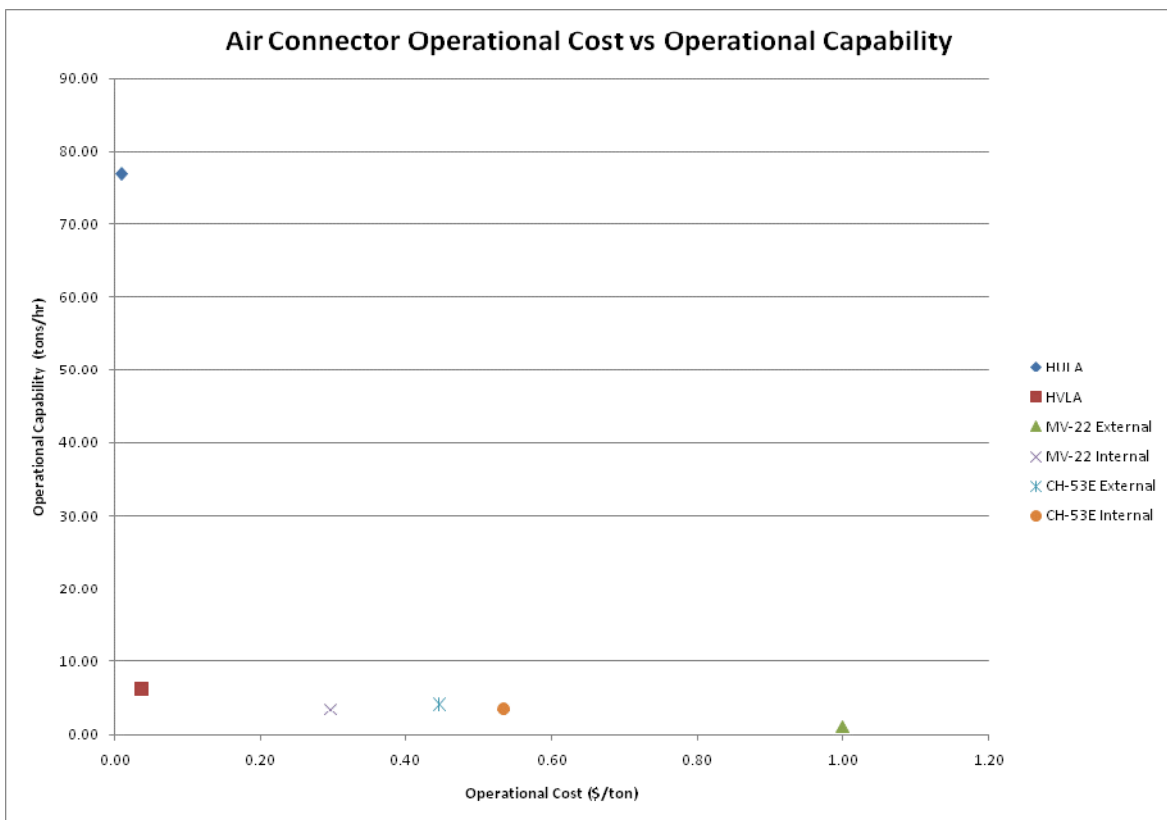
Figure 17.   Normalized Cost per Ton vs. Normalized Tons per Hour Plot of Air
Connectors.

Not surprisingly, from the results from this comparison, the connector possessing the lowest relative operational cost (N-$/ton) and the highest relative operational capability (N-TPH) is, by nearly a full order of magnitude, the HULA. Connectors such as the MV-22 when carrying external payloads does not fare nearly as well compared to the other air connectors. Somewhat misleading from this comparison is the appearance that utilizing both the MV-22 and CH-53E aircrafts configured for internal cargo payloads decreases their operational cost while increasing their operational capability. While, numerically, this is the case, the physical internal space available to either aircraft is the limiting constraint, and both aircraft would not be truly able to load internal cargo to the full weight capability of the aircraft. Effectively removing these two aircraft configurations shows that the HVLA, while possessing roughly the same order of magnitude in its operational capability as either the MV-22 or CH-53E costs considerably less than either the MV-22 or CH-53E.

VI. TRANSFER RATE EVALUATION

While not specifically analyzed in the context of this study, one important consideration in the success of any connector in completing its mission is the speed, or rate at which its payload can be loaded and unloaded. The data derived for this evaluation only includes those surface connectors possessing the ability to either deliver its cargo directly to the beach, in the case of the Landing Craft Utility, Replacement (LCU(R)), or to deliver its cargo to some other inland objective area in the case of the Landing Craft, Air Cushion (LCAC), Ship-to-shore Connector (SSC) and the Ultra Heavy-lift Amphibious Connector (UHAC).

Not included in this chapter's discussion are the air connectors contained in this study. In the case of the Hybrid Ultra-large Aircraft (HULA) and the Hybrid Very-large Aircraft (HVLA) loading and unloading times had not yet been estimated by Lockheed Martin, although it is assumed that the transfer rates for these air connectors would be comparable in magnitude to those values seen for the LCU(R) and UHAC. In the case of the vertical lift air connectors (i.e., MV-22 Osprey and CH-53E Sea Stallion), since the primary means of transporting cargo is accomplished using the external cargo hooks, the "load" and "unload" times are not applicable as those quantities are used to describe the physical loading and unloading of various types of cargo onto a connector, whereas for the MV-22 and CH-53E, these times are only a matter of hooking onto and dropping off whatever external cargo load is being carried.

A. SURFACE CONNECTOR TRANSFER RATE CALCULATIONS

As mentioned above, the surface connectors considered for these rate calculations are limited to the LCAC, LCU(R) and the UHAC. Table 11 shows the results of the calculations for both well deck transfer rates and beach transfer rates. Sample calculations are shown below in their respective sections utilizing the LCAC as the example. Calculations for the remaining connectors are done in the same manner.

Platform	Max Payload (Tons)	Well Deck Time (min)	Beach Time (min)	Well Deck Xft Rate (tons/hr)	Beach Xfr Rate (tons/hr)
LCAC	60	30	15	120	240
LCAC	75	40	20	112.5	225
SSC	74	40	20	111	222
LCU(R)	174	28	24	373	435
UHAC	240	29	19.5	497	738

Table 11.   Surface Connector Well Deck and Beach Transfer Rate Results Table.

1.   Well Deck Transfer Rate (WDTR)

The well deck transfer rate for each connector evaluated in this section is calculated by dividing the connector's maximum payload in tons by its average well deck time, expressed in hours. The results of this calculation provide a rough average of the connectors transfer rate while being loaded from any number of larger surface vessels with well deck capability (i.e., Mobil Landing Platform (MLP), Dock Landing Transport (LHD), etc.).

$$WDTR = \frac{60\,tons}{\dfrac{30\min}{60\min/hr}}$$

$$WDTR = 120\,tons/hr$$

2.   Beach Transfer Rate (BTR)

Much like the well deck transfer rate calculations, the beach transfer rate for each connector evaluated in this section is calculated by dividing the connector's maximum payload in tons by its average beach time, expressed in hours. The results of this calculation provide a rough average of the connectors transfer rate while offloading to a beach objective.

$$BTR = \frac{120\,tons}{\dfrac{15\min}{60\min/hr}}$$

$$BTR = 240\,tons/hr$$

B. SURFACE CONNECTOR TRANSFER RATES

The connectors maximum payload utilized in this section's calculations are as previously detailed in Chapter III.

1. Landing Craft, Air Cushion (LCAC)

In order to calculate the transfer rates described above, the average well deck and beach times, as seen in Table 11, needed to be established. For the LCAC, Naval Warfare Publication (NWP) 3-02.12, "Employment of Landing Craft Air Cushion (LCAC)" list the average well deck time as thirty minutes, and the average beach time as fifteen minutes.[69] These times represent an overall average time for a wide range of cargo types carried by the LCAC when loaded to its standard 60-ton payload.

The well deck and beach times for the LCAC, when loaded to its overload 75-ton payload, are increased by 10 and 5 minutes respectively to account for the additional time needed for the on-load and offload of the additional 15 tons, including the time needed to lash or unlash the additional payload. These times are as seen in Table 11.

2. Ship-to-shore Connector (SSC)

As with the LCAC, the well deck and beach times are needed for the SSC in order to calculate the two transfer rates of this chapter. The well deck and beach times for the SSC are assumed to be the same as for the LCAC when loaded to its overload 75-ton payload. As such, the two transfer rates for the SSC are as seen in Table 11.

3. Landing Craft Utility, Replacement (LCU(R))

The average well deck and beach times needed for the LCU(R) are taken from a CNA study entitled "LCU Replacement Analyses of Alternatives." As with the other connectors, these times represent overall average times for the various types of cargo carried by the LCU(R). The specific times are as seen in Table 11.

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[69] Navy Warfare Development Command, "Employment of Landing Craft Air Cushion."

4. Ultra Heavy-lift Amphibious Connector (UHAC)

As the UHAC is still a concept vessel, the average well deck and beach times needed for this study have not yet been evaluated or estimated. For the purpose of this study, the well deck and beach times for the UHAC are estimated by averaging the appropriate values of the LCAC loaded to its standard 60-ton payload and the LCU(R).[70] The results of these calculations are as seen in Table 11.

C. TRANSFER RATE SUMMARY

As seen from the values contained in Table 11, the average beach times are generally about half the time seen for average well deck times. This is primarily due to space restrictions available on the larger amphibious ship, rather than to the inherent design of any of the connectors. The values seen for average beach times also include an implicit assumption that there is no such space restriction and the connector's cargo can be offloaded at the maximum rate possible.

As mentioned above, the well deck and beach times listed in Table 11 represent the average time seen for the full range of cargo types carried by any given connector. Obviously, a payload consisting of all wheeled vehicles capable of loading or unloading under their own power will result in a much different time than a payload consisting of all palletized cargo. The palletized cargo requires the use of forklifts or other such equipment both on the loading ship as well as at the beach offloading site. If utilizing the transfer rates contained in this chapter, one must be conscious of these aspects and ensure that the cargo of any given connector is not exclusively one single type. If that is the case, then it is up to the user to modify the values contained in this chapter accordingly.

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[70] Based on phone conversations with Mr. Larry Johnson, Senior Project Manager, Fulcrum Corporation, July 2009.

VII. CONCLUSION

This report looks at a wide range of Sea-base connectors. In addition to considering both air and surface connectors, this report includes existing (legacy) connectors in use around the world today as well as future, concept connectors that are currently being developed and intended for use within approximately the next decade. As detailed in Chapter V, several metrics are used in the comparison of all connectors studied. These metrics include not only a connector's capabilities (maximum payload, maximum range and maximum speed) but also incorporate the average yearly Operating and Sustainment (O&S) cost of the connector. By including this cost value in the analysis, metrics such as cost per ton ($/ton) and cost per ton per nautical mile ($/ton-NM) are used in conjunction with non cost related metrics such as tons per hour (tons/hr) to systematically compare any number of connectors against each other. By comparing the connectors in this manner, some insight can be gained as to an individual connector's potential benefit when compared against any other, or any number of other connectors.

A.   CONNECTOR COMPARISONS

After comparing and analyzing the range of air and surface connectors considered in this report, as fully detailed and described in Chapter III, the following observations and take-aways are offered.

- The Joint High-speed Vessel (JHSV) initially appears to perform the best of the surface connectors studied. While numerically correct, it must be remembered that the JHSV still requires a dedicated port facility to offload its cargo provisions, as demonstrated in Figure 14. Because of this, it is felt that the JHSV would not be suited for use specifically as a Sea-base connector, but rather as an asset to be used to resupply the Sea-base itself, possibly from an advance base.

- Based on the metrics considered in this study, the Ship-to-shore Connector (SSC) numerically appears to fare slightly worse than the legacy Landing Craft Air Cushion (LCAC). While this is, in part, accurate, the true

benefit of the SSC over the LCAC is that the SSC is being designed for sustained near-maximum capability operation in weather up to and including Sea State 3, and at temperatures exceeding 100 degrees Fahrenheit. In contrast, the LCAC's designed operating temperature is only 80 degrees Fahrenheit, and its performance degrades in temperatures above that. More telling is that when the LCAC is loaded to its overload condition of 75 tons, as seen in Figure 18 as represented by the vertical dashed line labeled Maximum Allowable Weight, the LCACs maximum speed is severely degraded in conditions where the significant wave height exceeds four feet (Sea State 3).
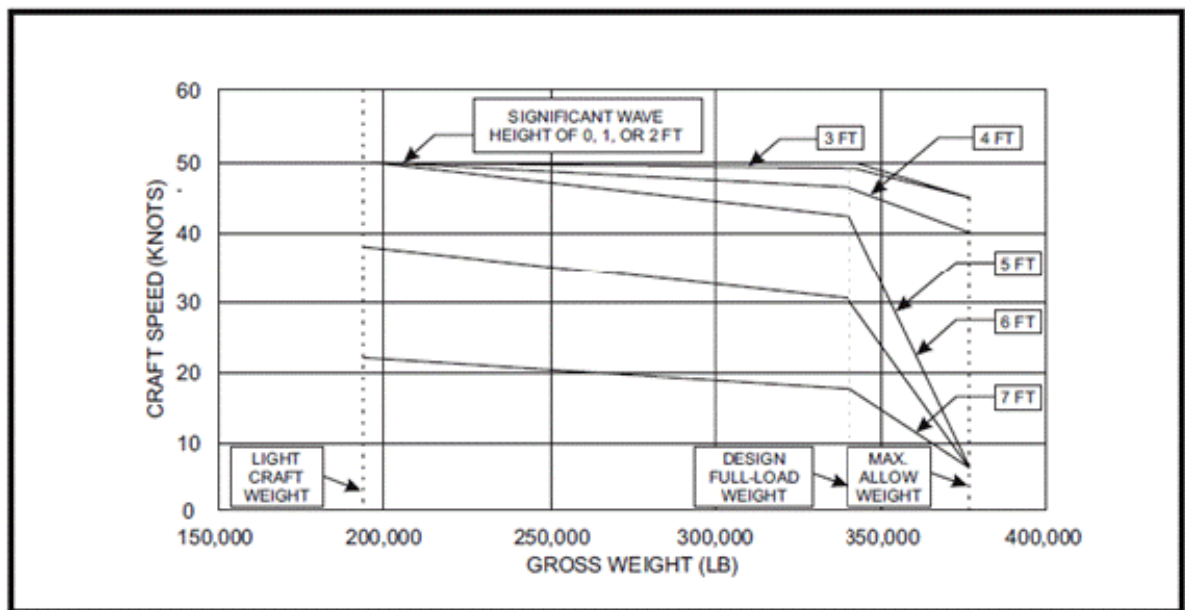

Figure 18.   LCAC Maximum Allowable Speeds. (From[71])

[71] Navy Warfare Development Command, "Employment of Landing Craft Air Cushion."

- Of the surface connectors studied in this report that possess the capability of delivering their payload directly to or across the beach (i.e., the LCAC, SSC, LCU(R), and UHAC) the UHAC shows the greatest potential, as seen in Figure 16. Based on the normalized quantities of Operational Cost ($/ton) and Operational Capability (tons/hr) from Figure 16, the UHAC has a cost of nearly four times lower than the LCAC and just over one and a half times the Operational Capability. From this, the UHAC appears to be the most advantageous surface connector studied and warrants continued analysis.

- Of all connectors studied in this report with the capability to deliver their payloads directly to or across the beach (i.e. all connectors except for the JHSV), the HULA shows the greatest potential as seen in Figure 13. Based on the normalized quantities of Operational Cost ($/ton) and Operational Capability (tons/hr) from Figure 13, the HULA has a cost several times lower than any other connector studied, and nearly eight times the Operational Capability. From these results, the HULA appears to be the most advantageous of any connector studied and warrants continued analysis.

- As a final comparison, using the best performing air and surface connector (HULA and UHAC), the maximum range, speed and payload were individually doubled while keeping all other parameters constant in order to get a sense of which parameter appeared to be the most relevant. Following this, combinations of two of the three parameters were doubled while holding the third constant for the same reason. Interestingly, as shown in Table 12, the doubling of a connectors range resulted in no difference from the initial calculations. However, the doubling of either the payload or speed resulted in half the normalized Operational Cost ($/ton) and a doubling in the Operational Capability (tons/hr). Additionally, the only combination of parameters which resulted in lower cost and higher capability was the one not involving range; that being

doubling of both speed and payload. As it is generally much more expensive to engineer a doubling of a vehicle's speed, it is felt that focusing on a doubling, or near doubling of a given connectors payload would be the most advantageous avenue to investigate.

Platform	Payload (Tons) - P	Speed (kts) - V	Range (Max)	norm. [$]/[ton]	norm. [tons/[hr]
UHAC (0)	240	22	200	0.02	8.12
UHAC (+range)	240	22	400	0.02	8.12
UHAC (+speed)	240	44	200	0.01	16.25
UHAC (+payload)	480	22	200	0.01	16.25
UHAC (+spd/rng)	240	44	400	0.01	16.25
UHAC (+rng/pyld)	480	22	400	0.01	16.25
UHAC (+spd/pyld)	480	44	200	0.0056	32.49
HULA	500	100	6,000	0.01	76.92
HULA (+range)	500	100	12,000	$0.009	76.92
HULA (+speed)	500	200	6,000	$0.005	153.85
HULA (+payload)	1,000	100	6,000	$0.005	153.85
HULA (+spd/rng)	500	200	12,000	$0.005	153.85
HULA (+rng/pyld)	1,000	100	12,000	$0.005	153.85
HULA (+spd/pyld)	1000	200	6,000	$0.002	307.69

Table 12.   Modified Ultra Heavy-lift Amphibious Connector (UHAC) and Hybrid Ultra-large Aircraft Performance Characteristics.

B.   RECOMMENDATIONS FOR FURTHER STUDY

The following areas are recommended for consideration of further study.

- Optimization of connector cost on a cost per hour ($/hour) basis was not pursued in this report beyond the limited cost data provided by Mr. Sam Klooster in regards to the Hybrid Very-large Aircraft (HVLA). Further studies should investigate the range of annual connector operating hours resulting in the best cost per hour value.

- The interaction between connectors and specific Sea-base platforms, such as the Mobil Landing Platform (MLP), was not considered in this study.

Simulations utilizing the MATLAB code developed by Professor Joshua Gordis, Naval Postgraduate School should be used in conjunction with the connector data contained in this report to investigate the best mix of available air and surface connectors to accomplish a specific mission objective.

- Cargo transfer rates between Sea-base platforms and Sea-base connectors and between Sea-base connectors and objective areas were not fully investigated in this report. As significant delays and bottlenecks can occur as a result of cargo transfer rates, further study should be conducted in this area to help identify potential mission degrading points.

- Further study should be conducted in the area of cost estimates. The data contained in this report utilizes open source cost information, and estimates based on conceptual connectors. As these newer technologies progress through the development and acquisition phases, refined cost estimates should be available to assist in further refining the outcomes of this report.

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LIST OF REFERENCES

Bradley, Ethel R. S., Lieutenant, USN. "Physics-Based Modeling and Assessment of Ship-to-Objective Maneuver (STOM) with Air and Surface Connectors," Master's thesis, Naval Postgraduate School, Monterey, California, March 2009.

"CH-53E Super Stallion," http://www.globalsecutiry.org/military/systems/aircraft/ch-53e.htm (accessed March 2009).

Cusic, Rod and Boyd, Robert, Lockheed Martin Advanced Development Programs "Hybrid Aircraft: A Different Look at Transportation," Lockheed Martin Corporation.

Fisher, Dan, Lockheed Martin Aeronautics Company, "White Paper – Hybrid Aircraft Survivability," Lockheed Martin Aeronautics Company, 01 November 2006, Lockheed Martin Corporation.

"Heavy lift Landing Craft Air Cushioned (HLAC)," http://www.globalsecurity.org/military/systems/ship/hlcac.htm (accessed March 2009).

"High Speed Vessel (HSV)," http://www.globalsecutiry.org/military/systems/ship/hsv.htm (accessed March 2009).

"High Speed Vessel Experimental One (HSV-X1), Joint Venture," https://ryan.delariviere.net/photo/d/15967-2/High_Speed_Vessel_Experimental_One_HSV_X1_Joint_Venture_02.jpg (accessed May 2009).

High-Speed Vessel 2, SWIFT, Offloading Cargo to a Pier, http://www.globalsecurity.org/military/systems/ship/images/hsv-2_050130-n-8629m-095.jpg (accessed 21 July 2009).

International Air Transport Association, Jet Fuel Price Monitor, http://www.iata.org/whatwedo/economics/fuel_monitor/index.htm (accessed April 2009).

Kusek, Pete, et al., "LCU Replacement Analyses of Alternatives," Center for Naval Analysis (CNA), CRM D0005604.A4/1Rev, August 2002.

"Landing Craft, Air Cushion (LCAC)," http://www.globalsecurity.org/military/systems/ship/lcac.htm (accessed March 2009).

"Landing Craft, Air Cushion (LCAC)," http://www.globalsecurity.org/military/systems/ship/images/lcac-2568s003.jpg (accessed 30 July 2009).

 "Landing Craft Utility (LCU)," http://www.globalsecutiry.org/military/systems/ship/lcu-x.htm (accessed March 2009).

Main, Geoffrey, Dr., ONR Code 333, "Ultra Heavy-Lift Amphibious Connector (UHAC) INP Concept," 22 May 2009.

Naval Air Systems Command, "NATOPS FLIGHT MANUAL NAVY MODEL CH-53E HELICOPTER," A1-H53BE-NFM-000, 15 March 2006.

Naval Air Systems Command, "NATOPS FLIGHT MANUAL NAVY MODEL MV-22B TILTROTOR," A1-V22AB-NFM-000, 01 October 2006.

Navy Cost Analysis Division (NCAD), http://www.ncca.navy.mil/services/inflation.cfm (accessed April 2009).

Navy Warfare Development Command, "Seabasing," NWP 3-62M, August 2006.

Navy Warfare Development Command, "Employment of Landing Craft Air Cushion (LCAC)," NWP 3-02. 12, February 1997.

"Online Conversions," http://www.onlineconversion.com (accessed April 2009).

Partos, Dana S. and Kurtz, James S., Center for Naval Analysis, "Cost-Benefit Methodology for Seabasing and Expeditionary Lift," CAB D0014180.A2/Final, July 2006

"Ship-to-Shore Connector for Technical Studies," https://www.fbo.gov/index?s=opportunity&mode=form&id=582f8346309854223cb9bf5aaeb35baf&tab=core&_cview=0 (accessed 27 May 2009).

Systems Engineering and Analysis-6 Cohort, "Seabasing and Joint Expeditionary Logistics," Master's thesis, Naval Postgraduate School, Monterey, California, December 2004.

VAMOSC is a restricted access system. Access permission must to granted by the NCAD. The VAMOSC system is located at http://www.navyvamosc.com/ (accessed 02 April 2009).

Williams, Christopher G., Lieutenant Commander, USN, "Physics-Based Modeling and Assessment of Mobile Landing Platform System Design," Master's thesis, Naval Postgraduate School, Monterey, California, September 2008.

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